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EVALUATION OF MANAGEMENT PRACTICES ON THE BIOLOGICAL AND CHEMICAL CHARACTERISTICS OF STREAMFLOW FROM FORESTED WATERSHEDS

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ON LAND & WATER RESOURCES

THE PENNSYLVANIA STATE UNIVERSITY

Prepared for

OFFICE OF WATER RESEARCH AND TECHNOLOGY

DEPARTMENT OF THE INTERIOR

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Research Project Technical Completion Report

The work upon which this report is based was supported in part by federal funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized under the Water Research and Development Act of 1978, as amended through annual allotment agreement number 14-34-0001-1140. This constitutes the final technical completion report for project A-041-PA. Non-Federal support was provided in part by the Pennsylvania Department of Environmental Resources under agreement number ME 75801.

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University Park, PA 16802

November 1980

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ABSTRACT

A 106-acre oak-hickory experimental watershed in central Pennsylvania was clearcut in three phases to evaluate the effects of the clearcuts on the physical, chemical, and biological properties of streamflow. Herbicides were used to control the regrowth of vegetation so that groundcover conditions on the clearcuts would be similar for each phase analysis, and also to quantify maximum response and stress factors. The watershed response to these treatments was characterized by measuring changes in streamflow amounts and timing, stormflow parameters, streamwater temperature, nutrient concentrations, turbidity and sediment, and aquatic macro-invertebrate populations. Biologic implications for the aquatic ecosystem are presented on the basis that each aquatic organism has a particular set of environmental conditions and habitat preferences that are optimal for its maintenance.

CONCLUSIONS

1. Removal of the forest vegetation significantly increased stream discharge. Increased yield was greatest during the growing season months of June, July, August and September. As much as 15 inches of additional water per year on an area cut basis was produced from the lower slope clearcut. The water yield increases produced by the middle slope and upper slope clearcuts were proportionately less.

2. Removal of the forest vegetation had little effect on dormant season stream flow.

3. The magnitude of the response of the stream regime to the clearcut herbicide treatments was controlled by the size of the area cut and the amount and distribution of rainfall.

4. Flows in the low to medium discharge classes were most affected by the treatment. The range of flow classes affected was related to the proportion of the watershed cut.

5. Maximum summer peakflows were significantly increased by the clearcut-herbicide treatments. The magnitude of the increases in summer peakflows was closely related to the proportion of the watershed cut. Peakflows in the low to medium discharge classes (below 3.0 csm) were most affected, although peakflows above 3.0 csm also increased.

6. The stream temperature regime on the treated watershed was severely affected. Average monthly maximum temperatures increased as much as 19°F. Temperatures as high as 89°F were measured. Significant temperature changes occurred as early as March and as late as November.

7. Minimum streamwater temperatures were increased for all months studied except November, where a 7°F decline was measured.

8. Cooler ground water inflow and radiational cooling reduced the increased temperatures (500 yards below the clearcut) to near those on the control watershed.

9. Clearcutting substantially increased diel temperature fluctuation. Fluctuations as high as 31°F were measured.

10. Turbidity and sediment levels increased as a result of logging. Although the highest levels occurred during logging, increased stream discharge, particularly storm flows, caused severe channel cutting and bank slumping, which resulted in increased sedimentation over the entire post-treatment period. Stabilization of the channel area has not yet occurred due to the increased frequency of low and medium peak stormflows.

11. Nutrient concentrations showed a variable response to treatment. Only potassium and nitrate-nitrogen were significantly increased consistently over the study period.

12. The magnitude and duration of the changes in nutrient concentrations were directly related to the elimination of the vegetative cover by herbicides. Rapid revegetation of the cutover area reduced the nutrient concentrations to near pre-herbiciding levels within one year.

13. Nutrient concentrations generally increased form the headwater to the mouth of the watershed and reflected the geology over which the stream passed and the opportunity for nutrient leaching.

14. Increases in nutrient loading were slight, irregular and temporary. Export of nutrients from the site was insufficient to cause stream eutrophication.

15. Significant decreases occurred in 11 of 44 taxa of macro-invertebrates following the application of herbicides to the lower and middle slope clearcut. It was impossible to determine if the depletion was due to the herbicides themselves or to a combination of increased discharge, stream temperature, and turbidity and sedimentation.

16. Changes in stream temperature, turbidity, and sediment have had a deleterious affect on the biological community inhabiting the streams. Increased stream discharge (especially during the summer months) and dissolved nutrients may have been beneficial to the biological community. However, for these beneficial effects to be fully utilized, additional protection of the streamside zone, to moderate temperature and sediment increases, would be necessary.

INTRODUCTION

Urbanization in the Northeast has created drastic environmental changes through modification of the natural landscape. This in turn has significantly altered both the quantity and quality of our water resources at a time when we are experiencing unprecedented demands for high quality water for domestic, industrial, and recreational use. As population and economic activity increase in the Northeast, water demands will also increase. Coupled with this is the steady upgrading and shifting of objectives in our affluent society. It is not enough merely to supply the water; it must be supplied in a manner that maintains a quality environment and considers aesthetic and cultural values. In view of these facts The Water Resources Council (1968), in their assessment of the Nation's water resources, indicated that an adequate water supply and improvement of water quality are among the most urgent problems requiring immediate attention. One of the items given high priority was the incorporation of watershed land management as an integral function of water resources planning and development.

The Northeastern United States offers perhaps more opportunities for forest water-yield management than any other region. This region not only contains the largest urbanized complex in the nation but also a sizable forest area. Located within this region are about 2,000,000 acres of watershed land that are owned or controlled by over 750 municipalities, private water companies, and State and Federal agencies that serve about one-third of the region's population (Corbett, 1970).

In Pennsylvania, forests cover more than half of the land area and hence receive a large portion of the State's precipitation. Moreover, since these forest areas generally occupy mountainous lands, they serve as collection basins for many of the State's municipal water supply systems and exert a major influence on the continuity and quality of streamflow. Thus, one approach to solving our water problems depends upon research directed towards augmenting high quality water supplied through forest management practices.

The need to plan and develop our water resources was underscored in the Northeast by the 1961-66 drought and reflected in a survey of Northeastern watershed managers (Corbett, 1970) in which 53 percent considered water-yield improvement as a major problem area. In addition, changing attitudes and inflationary costs have prompted watershed managers to use their timber resource better. As a result, many municipalities are actively managing their timber resources to provide additional revenue and augment water supplies. This occurs at a time when both State and Federal regulatory agencies are enforcing more stringent water quality standards -- i.e., the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500),

the Safe Drinking Water Act of 1974 (P.L. 93-523), the 1977 Clean Water Act (P.L. 95-217), and State regulations such as the Pennsylvania Clean Streams Law. Continual upgrading of water quality standards are a sure sign that methods used to harvest timber in the future must assure adequate protection of our watersheds.

To evaluate forest management effects on water supply and water quality parameters, the Leading Ridge Experimental Watershed Research Unit was established in 1957. It is part of a cooperative research project of The Pennsylvania State University; The Pennsylvania Department of Environmental Resources, Bureau of Forestry; and the Northeastern Forest Experiment Station, U.S. Forest Service. This project investigated the pertinent factors that influence the quality and quantity of water yielded from forested lands and evaluated the effects of clearcutting and herbiciding forest vegetation on these parameters.

RELATED LITERATURE

Water Quality

Clearcutting effects on water quality can be divided into categories: (1) changes in water temperature, (2) changes in stream turbidity and sediment loading, and (3) changes in nutrient concentrations. In turn, these changes may affect downstream use for water supplies and for recreational activities such as fishing and swimming.

Water Temperature

The effect of clearcutting on water temperature is directly related to the surface area of stream exposed to direct sunlight. This is due primarily to the energy increase created when the low-intensity, diffuse light of a stream under the forest is changed by canopy removal to direct solar radiation (Levno and Rothacher, 1967).

Prior to 1950, the effect of clearcutting on the water temperature of small, mountain streams was considered remote and inconsequential. Since then, a number of studies have shown a substantial change in water temperature of a stream after the surrounding vegetation had been cut.

On the Fernow Experimental Forest near Parsons, West Virginia (representative of the major hardwood types found in the central Appalachians), average stream temperatures during the first growing season following cutting were 8°F higher (59° to 67°F) on an east-facing commercially clearcut (74 acres) watershed than they were on the control. The highest water temperature recorded on the clearcut watershed was 79°F; however, numerous temperatures above 75°F were observed (Eschner and Larmoyeux, 1963). As a result of regrowth, stream temperatures returned to precutting levels within five years following cutting (Kochenderfer and Aubertin, 1975).

Other studies conducted on the Fernow Experimental Forest have shown similar results. Maximum growing season stream temperatures for a south-facing watershed (54 acres) on which the lower one-half was clearcut and herbicided averaged 10°F higher than the control watershed. On an east-facing watershed (59 acres), where the clearcut operation of the lower one-half left the stream partly covered by slash that shaded the channel, the maximum growing season stream temperatures averaged 4°F higher than the control. The marked difference between the results of deforesting/herbiciding the lower halves of these watersheds reflect orientation and the harvesting techniques employed. Deforesting/herbiciding the upper halves of these watersheds had no appreciable effect on stream temperatures. However, no additional stream channels were exposed to direct radiation on the deforested upper halves (Kochenderfer and Aubertin, 1975).

On the Hubbard Brook Experimental Watersheds in New Hampshire, Likens et al., (1970) noted higher stream temperatures in a completely deforested area than in the control area. Maximum growing season stream temperature in the treated area was 71°F while the control stream never exceeded 59°F.

At the Coweeta Hydrologic Laboratory near Franklin, North Carolina, stream temperature increases as high as 20°F (65° to 85°F) were observed following the clearcutting and conversion of a deciduous watershed to farm land. However, in a less severe treatment in which the cove timber was first deadened prior to clearcutting the entire watershed, summer maximum stream temperatures increased only 6°F (65° to 71°F). The highest maximum stream temperature recorded was 74°F. Temperatures returned to pre-treatment levels in the fourth year (Swift and Messer, 1971).

Not only are maximum temperatures increased following clearcutting, the daily fluctuations are also increased. In a study in Oregon, reported by Brown and Krygier (1967), clearcutting resulted in a 14°F increase in the daily fluctuation in water temperature of a small mountain stream. Similar results were reported by Swift and Messer (1971) when they observed an increase in the daily difference between the maximum and minimum temperature from 3.9°F to 8.5°F. This increase followed the clearcutting of a 40-acre south-facing watershed.

The increase in water temperature and daily fluctuations is moderated downstream from the clearcut. This was first demonstrated by Greene (1950) when he compared stream temperatures of farm and forested watersheds in the mountains of North Carolina. Maximum temperatures for the farm stream varied from 65°F to 79°F, whereas the forest stream temperatures never exceeded 66°F. Stream temperatures in the farm stream dropped from 79°F to 68°F after meandering 400 feet through the forest and brush cover.

The importance of overhead shade has also been demonstrated by Swift and Messer (1971). Based on studies in North Carolina, they found that in clearcut areas where streambank vegetation was uncut, summer maximum water temperatures remained unchanged when compared with a control watershed. Where streambank vegetation had regrown following a clearcutting 8 years previously, summer maximum water temperatures were even lower than those under uncut, mature hardwood forests. This was attributed to the dense shading caused by sprout growth which developed following cutting. They concluded that the magnitude of water temperature increase depends upon the degree of vegetation removed along the stream. A similar conclusion was also reached by Levno and Rothacher (1967) based on a series of cuttings on the H.J. Andrew Experimental Forest in Oregon.

Another such study, conducted in Oregon and reported by Brown and Krygier (1967), showed water temperature increases as early as May of 16°F (52° to 68°F) from the time the stream entered the clearcut until it left the area (1,300 feet). However, after the stream had

passed under 700 feet of undisturbed canopy, maximum water temperatures were reduced as much as 8°F, indicating considerable cooling in the shaded stretch. However, Brown, Swank, and Rothacher (1971) later concluded from another study in Oregon that "shaded reaches downstream from a clearcut cannot be relied on to cool heated streams. Cooling that does occur can often be attributed primarily to inflow and mixing of cooler ground water."

Recently the concept of buffer strips has been getting a great deal of attention as a method of protecting streams and stream life in timber-producing forests. The idea is to leave a strip of relatively undisturbed vegetation along the banks of streams at the time adjacent lands are logged so that this strip may "buffer" the stream from such adverse effects as siltation, slash and debris accumulation, and temperature increases.

Bengeyfield (1973), while working with streams in West Virginia, found that weekly maximum stream temperatures on the control and clearcut with buffer zone watersheds were essentially the same during the summer months. The average difference between them was 0.8°F, with the control watershed being slightly cooler. During the same period, the maximum temperatures on a clearcut watershed that had no buffer zone averaged 11°F higher than the control. The highest maximum stream temperature was 77.5°F.

Brown, Swank, and Rothacher (1971) reported the results of an Oregon study in which stream temperatures were increased as much as 10°F when all shade was removed from a stream. Where a buffer strip was used stream temperatures showed no increase when compared to a control watershed.

Encouraged by the results of this study, Brazier and Brown (1973) initiated a study aimed at defining the characteristics of buffer strips that are important in regulating the temperature of small streams. They were also interested in describing a method of designing buffer strips that would insure no change in stream temperatures and, at the same time, minimize the amount of commercial timber left in the buffer strip. From the results of this study they concluded that commercial timber volume alone is not an important criterion for temperature control. For the streams studied, they found that the maximum shading ability of the average strip was reached within a width of 80 feet; 90 percent of that maximum was reached within 55 feet. Specifing standard 100- to 200-foot buffer strips for all streams which usually assures protection, generally will include more timber in the strip than necessary.

The studies reported herein do illustrate the effect that maximum vegetative clearance has on summer temperatures of small streams unless precautions are taken. Such high temperatures adversely influence water by affecting a wide range of physical, chemical, and biological processes.

Stream Turbidity and Sediment Loading

The effects of forest treatments on the sediment load carried by streams vary considerably. Some forest areas can undergo severe treatment and remain relatively stable. Others erode severely after only slight distrubance. Such differences in the hydrologic behavior and stability characteristics of forest lands can usually be traced to variations in climate, topography, geology, and soils. These variations tend to be balanced by vegetation in ways that provide stable soils in most forest regions. Studies conducted at Penn State, Coweeta, Fernow, and Hubbard Brook have illustrated this interaction between the soil and vegetation. Streamflow turbidities from undistrubed watersheds on the four experimental forests have been less than 5 ppm during nonstorm periods and no greater than 11 ppm during heavy storms (Dils, 1957; Sopper and Lynch, 1970; Reinhart et al., 1963; Lull and Reinhart, 1963).

The effects of timber cutting itself (unconfounded by the skidding and road building disturbances) has little if any effect on the turbidity of streams (Bates and Henry, 1928; Hoover, 1944; Lieberman and Hoover, 1951; and Likens et al., 1970). However, when the effects of timber cutting are combined with those effects caused by improper logging or road construction, the quality of water deteriorates. Numerous studies throughout the United States have emphasized the seriousness of this problem. The results of these studies have been summarized by Packer (1967).

The effect of logging in the East on stream turbidity was illustrated by a study conducted on the Fernow Experimental Forest. Reinhart, Eschner, and Trimble (1963) observed serious pollution when logger's choice skidroads with few if any drainage facilities were used on a commercial clearcut and a diameter limit cut. Maximum turbidities were 56,000 and 5,200 ppm respectively. On extensive and intensive selection cuts, with carefully constructed skidroads and water bars, maximum turbidity reached only 210 and 25 ppm respectively during cutting and subsided almost immediately after logging ceased. Maximum turbidity on the control watershed never exceeded 15 ppm. Regardless of the logging practice employed, the impact of cutting on stream turbidity was greatest during and immediately after logging.

Leiberman and Hoover (1948) reported on the increased turbidity resulting from clearcutting a 212-acre watershed on the Coweeta Hydrologic Laboratory. Average turbidity ranged from 4.3 ppm on the control to 93.7 ppm on the treated area while maximum turbidity ranged from 80 ppm (control) to 3,500 ppm (treated). In this study no restrictions were placed on cutting practices or construction and layout of roads. The greatest erosion and resulting high turbidity occurred while the actual logging was in progress on the watershed.

Hall and Lantz (1969) noted a significant increase in the sediment load of a stream flowing from a clearcut on the Alsea watershed in Oregon. Average storm concentrations of suspended sediment during the two winters following logging increased 3 to 4 times over the

prelogging values. Increases in sedimentation from a patch cut watershed with buffer strips, while noticeable, were much below those of the clearcut area. Portions of the increased sediment on the clearcut watershed were from stream debris removal operations.

In general, bare soil exposed by road building, and to a much lesser extent by log landings, has long been recognized as the major source of stream sediments associated with logging operations. Careless logging can cause very turbid water, while logging on carefully located, constructed, and maintained road systems and skid trails result in only minor increases in turbidity.

Nutrient Concentrations

The effects of clearcutting on nutrient discharge in streamflow attracted widespread attention after experimental results on the Hubbard Brook Experimental Forest in the White Mountains in New Hampshire were published (Bormann *et al.*, 1968). Here a 39-acre watershed was completely deforested. All trees and other woody vegetation were left in place. For the next three summers the entire watershed was sprayed with herbicides to eliminate the regrowth of vegetation. It should be emphasized that this experiment was not designed to simulate a normal forest cutting and logging operation, but was used solely for watershed research purposes.

Following treatment, discharge of some nutrients in streamwater was surprisingly high. The concentration of nitrates in streamwater rose from a maximum 2 ppm before treatment of 90 ppm after the forest cutting. Concentrations of ions, such as calcium, magnesium, and potassium, varied from 5 to 30 times above normal (Pierce *et al.*, 1972). These increases were attributed to (1) exposure of the site to greater-than-normal amounts of heat and water, thereby accelerating soil decomposition and subsequent leaching of nutrients, (2) acceleration of the nitrification process, and (3) blocking the uptake of available nutrients that normally would have occurred had vegetation been allowed to regrow (Pierce *et al.*, 1972). A fourth factor advanced by Reinhart (1973) is the large accumulations of organic matter on the surface and in mineral horizons that are generally low in available nutrients and possibly low in ability to retain nutrients.

Nutrient losses from actual timber harvest clearcuts on the White Mountain National Forest in New Hampshire have been found to be much lower. Watershed averages for nitrate concentrations in the streamwater ranged from 5.8 to 19.9 ppm; the maximum recorded value was 28.4 ppm. Measurements made further downstream illustrated the dilution provided by essentially nutrient-free water from areas not cut. On one sampling occasion, the nitrate concentration in streamwater draining at 160-acre clearcut was 19.0 ppm; at a point downstream, for which the total drainage area was 240 acres (160 cut, 80 uncut), the concentration was only 10.7 ppm (Pierce *et al.*, 1972).

In the Appalachians, where soil conditions differ from those of Hubbard Brook, nutrient discharges were far less following a timber-harvest clearcut. In the first year after harvest on the Fernow Experimental Forest, average nitrate concentration in streamwater was only 0.9 ppm for the growing season and 2.2 ppm for the dormant season; the maximum recorded was 6.2 ppm (Aubertin and Patric, 1972). Calcium, magnesium, potassium, and sodium were also found to be little affected by clearcutting (Kochenderfer and Aubertin, 1975).

Although slight, local, and temporary eutrophication of streamflow was noted in the New Hampshire studies, this stream enrichment was diluted by inflow from the uncut portion of the drainage. In some cases enrichments of streams may be beneficial, particularly in streams that are relatively devoid of dissolved nutrients in their natural state. These increased nutrients in streamwater may support plant and animal life that previously existed at low population levels or was nonexistent (Pierce _et al_., 1972). Long-term effects of nutrient leaching on site productivity have not been quantified.

OBJECTIVE

The basic objective of this study was to evaluate the effects of forest clearcutting and herbicide vegetation control on the physical, chemical, and biological properties of streamflow. The close relationship between stream discharge and water quality also required the evaluation of the impact of the clearcut-herbicide treatment on water yield and timing.

DESCRIPTION OF WATERSHED UNIT

This research was conducted on the Leading Ridge Experimental Watershed Research Unit of The Pennsylvania State University (Figure 1). These watersheds were established in 1957 to investigate basic forest-soil - water relationships and to evaluate the effects of vegetation management on water supply and water quality parameters. These watersheds, which lie in the Ridge And Valley Province of central Pennsylvania, are representative of approximately 10 million acres of Pennsylvania forest land, much of which lies within established municipal watershed boundaries.

The Leading Ridge Watershed Research Unit is maintained and operated by the School of Forest Resources, The Pennsylvania State University, as an outdoor hydrologic laboratory for instruction and research in Forest Hydrology and Forest Watershed Management. It consists of three adjacent watersheds which are 303, 257, and 106 acres in area.

On all three watersheds, modified broad-crested Trenton weirs with a sharp-crested, 90-degree, V-notch in the center are used to measure stream discharge. Each weir is 30 feet wide and has a total capacity of 117 cubic feet per second. The watersheds all have a southeastern aspect; they range in elevation from 900 to 1,450 feet. Mean slopes range from 12 to 17 percent. The watersheds are underlain by three major geological formations (Figure 2). The Rose Hill shale formation, which underlies most of the lower slopes of the watersheds, is approximately 700 feet thick. The upper part of the lower slope, middle slope, and most of the upper slope is underlain by Castanea sandstone having a thickness of approximately 500 feet, while Tuscarora quartzite underlies the ridge top.

Most of the soils are residual, having developed in place through the weathering of the underlying strata. A soil survey resulted in the classification of nine major soil types (Figure 3). Soils on the lower slopes are primarily silt and stony loams that are well-drained and have a high moisture-holding capacity. The middle and upper slopes are classified as cobbly and stony loams, which are

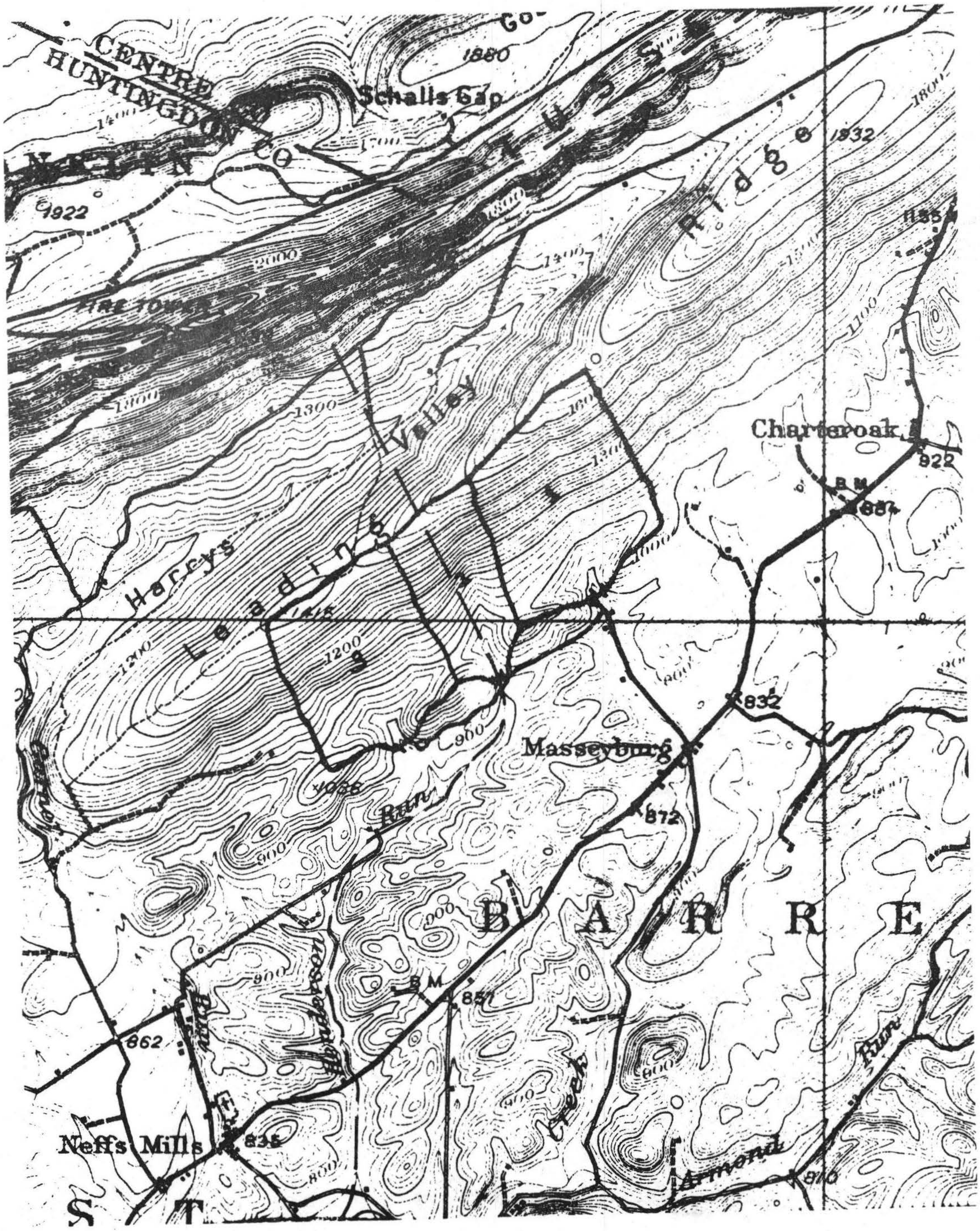
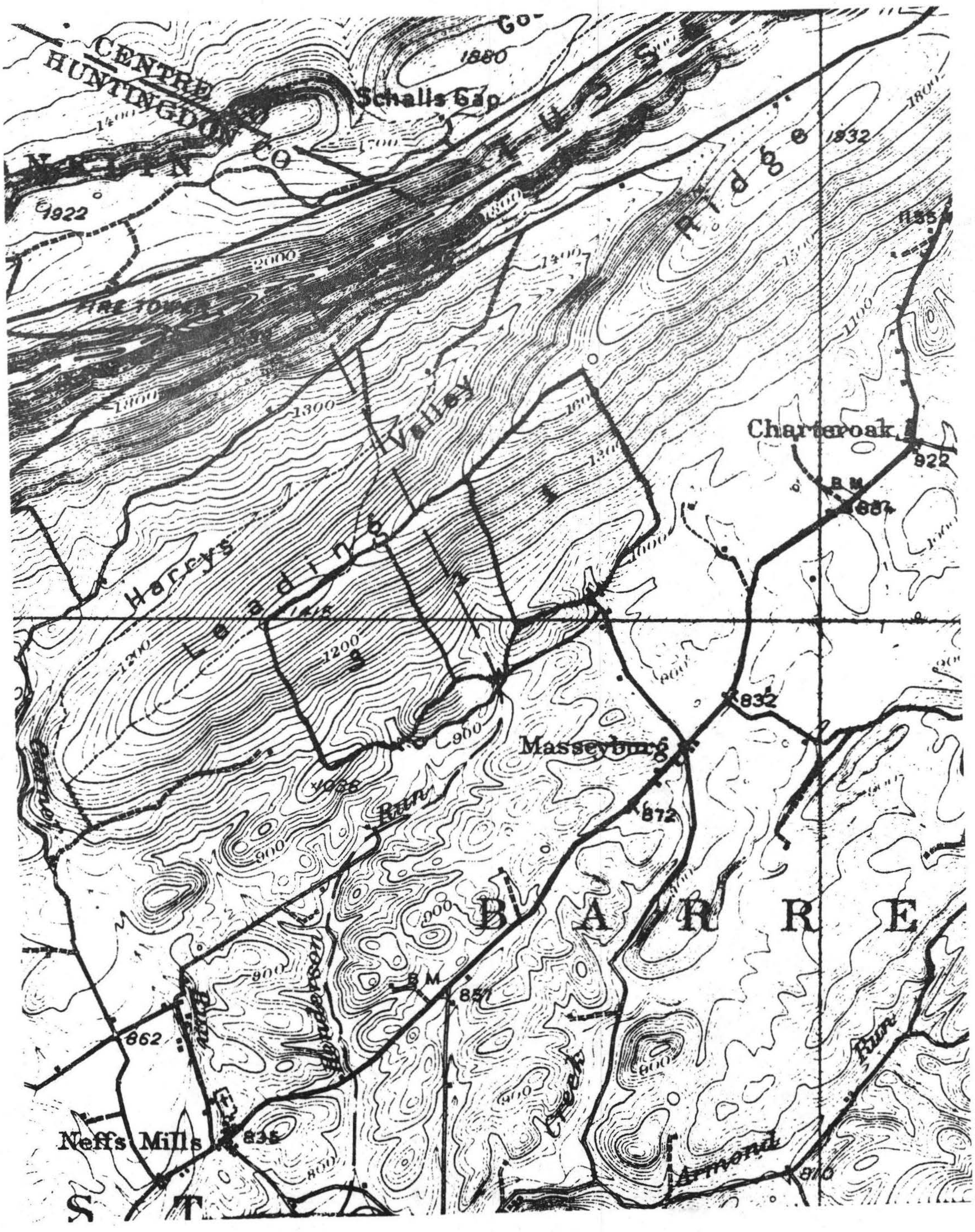


Figure 1. Map showing the location of the Leading Ridge Experimental Watershed Research Unit (U.S.G.S., Pine Grove Mills, PA Quadrangle).



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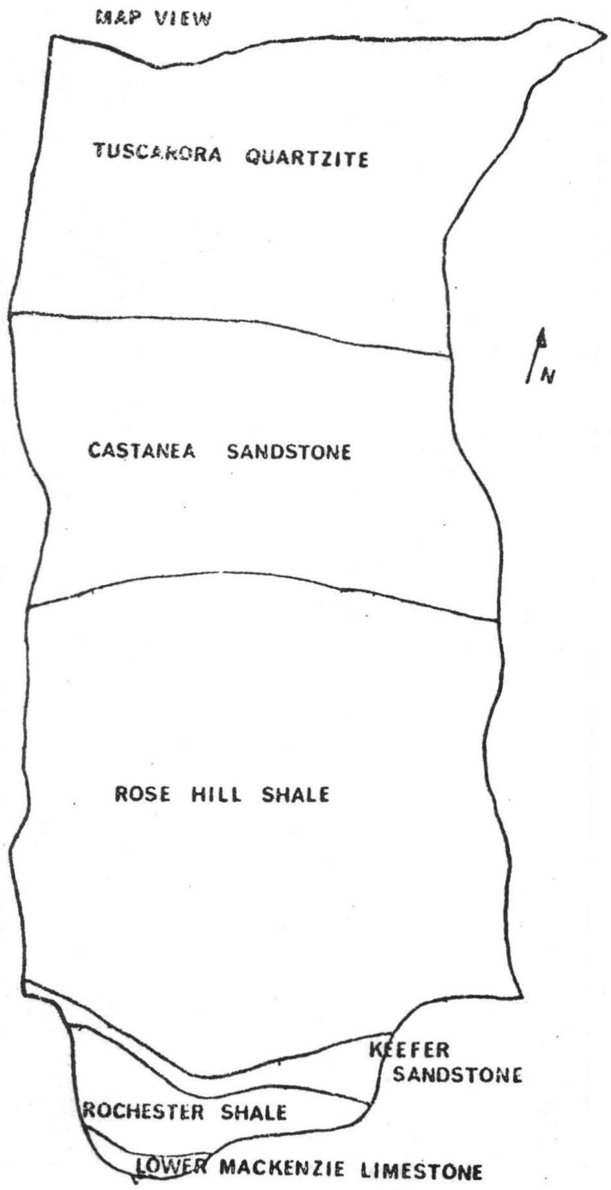
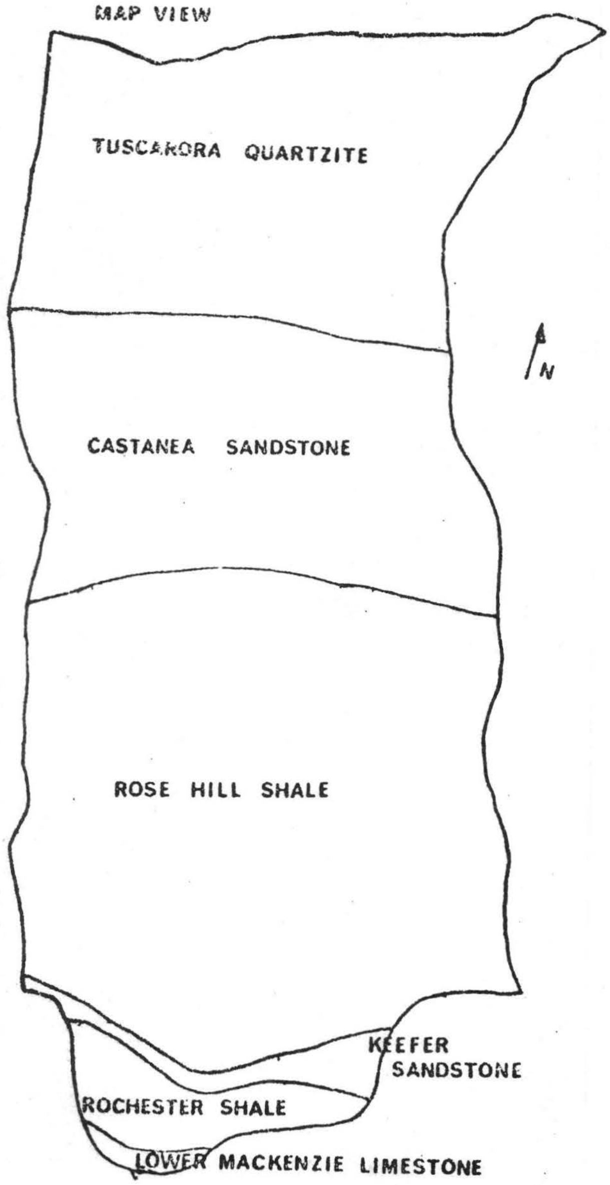


Figure 2. Geologic map of Leading Ridge Watershed Two.



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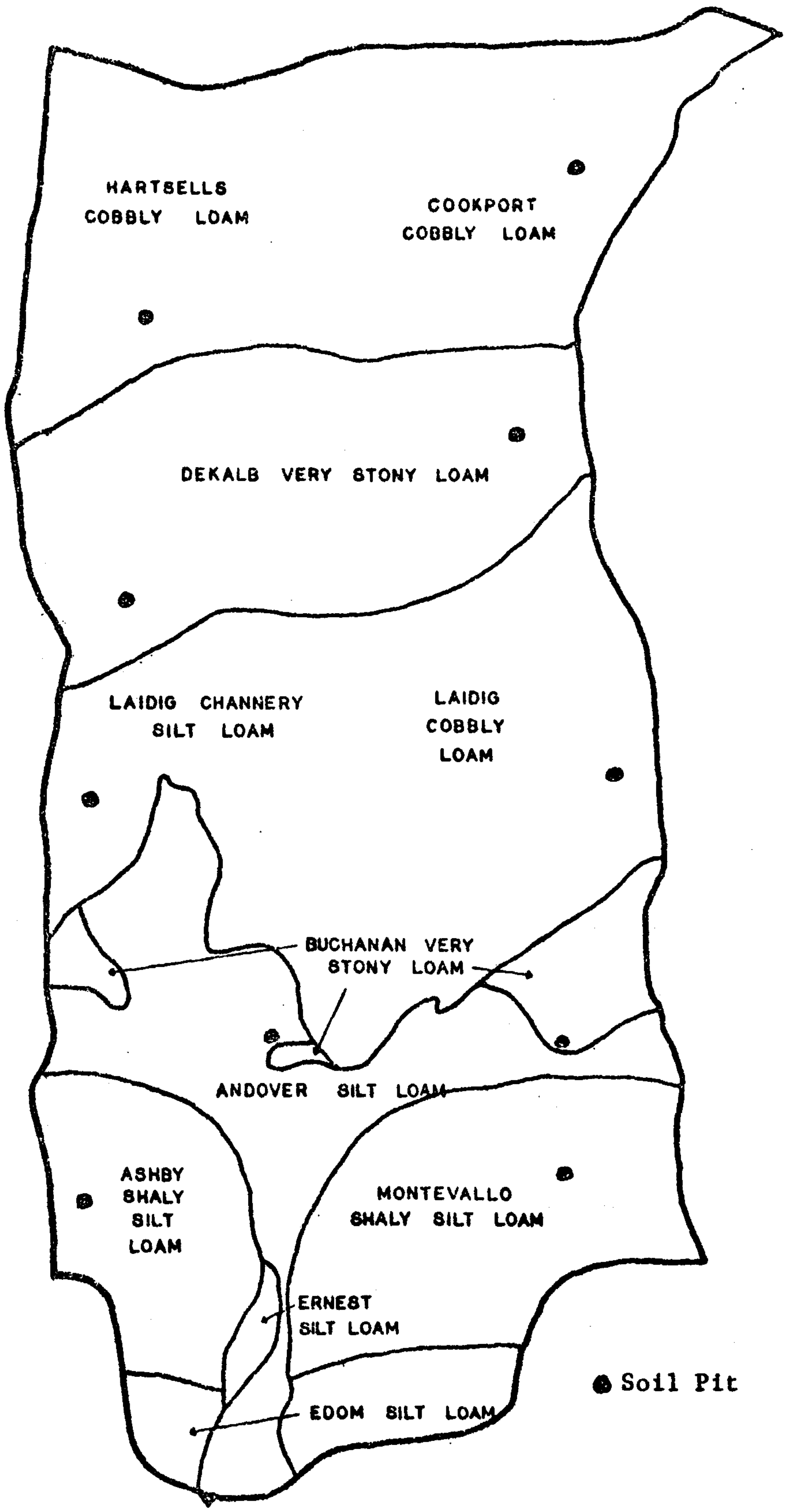


Figure 3. Soil map of Leading Ridge Watershed Two.

also well-drained. Rough, stony land covers the ridge top. The soil mantle generally ranges in depth from 3 to 5 feet.

The vegetative cover consists of an uneven-aged coppice forest of oak, hickorv, and manle. Predominant species are white oak (*Quercus alba* L.), red oak (*Q. ruba* Asche), and black oak (*Q. velutina* Lamb) on the lower and middle slopes. On the upper slopes and ridge top, the dominant species are chestnut oak (*Q. prinus* L.), with red oak, black oak, and pitch pine (*Pinus rigida* Mill) as associates. The subordinate layer consists of dogwood (*Cornus florida* L.), red maple (*Acer rubrum* L.), and witch hazel (*Hamamelis virginiana* L.).

RESEARCH APPROACH

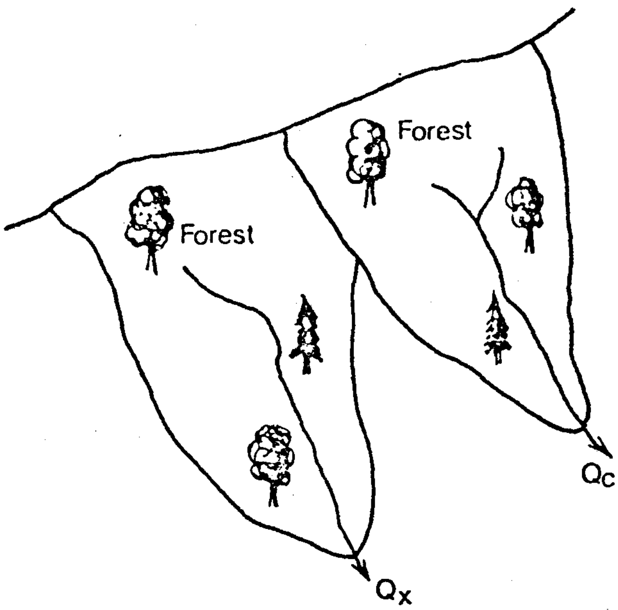
A modification of the basin water balance approach is the paired watershed method. Figure 4, adapted from Hewlett and Nutter (1969) illustrates the method. Two small watersheds (they may be from a few to several hundred acres) are selected to be gaged; both have the same type of vegetal cover and they should lie side by side or close together. One is to be the treated watershed (subscript x) and one is to be the control (subscript c). The experiment is divided into two successive periods, called the calibration period and the treatment period. The aim is to harvest and mature hardwood forest on watershed x and determine the change in annual streamflow (Q_x). Changes in other water quantity as well as water quality parameters can also be determined by this method.

The success of the method is based on the high degree of correlation that normally exists between Q_x and Q_c (the annual discharges from the two watersheds) when the vegetal cover is the same. This correlation is evaluated during the calibration period by regression analysis and the resulting "prediction equation" is used to determine the change in yield after the treatment. Since climatic changes are "controlled" by comparison with the undisturbed watershed, we may assume that the change in Q_x during the treatment period was due to a change in evapotranspiration from the treated watershed.

Following completion of a 7-year calibration period, a three-phase experiment involving the complete clearcutting-herbiciding of the 106-acre Leading Ridge Watershed Two was undertaken. A complete chronological history of Leading Ridge Two is given in Table 1. The purpose of each clearcutting was to determine the effects of removing forest cover from each area (lower slope, middle slope, and upper slope and ridge top) on water yield and quality.

Phase one (during the winter of 1966-67) involved the removal of 53,878 cubic feet of timber on 21.3 acres of the lower slope portion of Leading Ridge Watershed 2 (Table 2). This clearcut was essentially

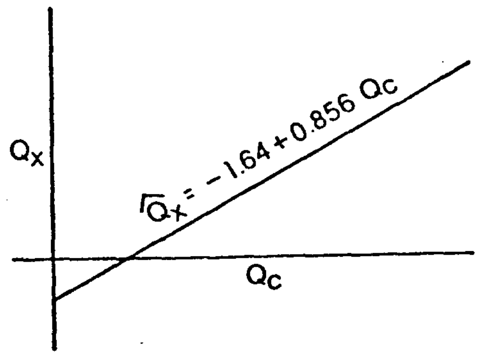
CALIBRATION PERIOD



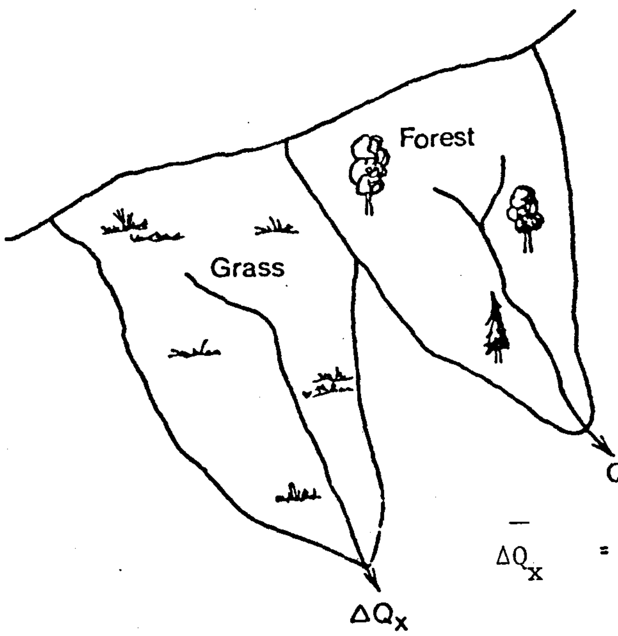
Streamflow in inches per year

Q_x	Q_c
20	25
12	16
23	29

To estimate $\hat{Q}_x$, the regression equation is computed:



TREATMENT PERIOD



Streamflow in inches per year

Q_x	Q_c	$\hat{Q}_x$	$(Q_x-\hat{Q}_x)$
24	20	15.5	8.5
18	16	12.1	7.0
24	24	19.0	5.0
			Sum = 20.5

To estimate the average change in Q_x due to treatment:

$$\overline{\Delta Q_x} = \frac{\sum(Q_x - \hat{Q}_x)}{3\text{ years}} = +\ 6.8\text{ inches}$$

Figure 4. A simplified example of a paired watershed experiment using regression analysis. The intercept and slope of the extimating equation are determined and the change in Q_x is computed as shown (Adapted from Hewlett and Nutter, 1969.).

Table 1. Chronological history of treatments on Leading Ridge Watershed Two.

Period	Treatment
May 1, 1959 to December 31, 1966	Calibration period
January 1, 1967 to April 30, 1967	Twenty-one acres clearcut on lower slope
May 1, 1967 to October 31, 1971	Lower slope post-treatment period
November 1, 1971 to April 30, 1972	Additional 27 acres clearcut on middle slope
June 3, 1974	Entire 48 acres clearcut sprayed with herbicides
May 1, 1972 to October 31, 1975	Lower and middle slope post-treatment period
November 1, 1975 to April 30, 1976	Additional 42 acres clearcut on upper slope and ridge top
June 6, 1977	Entire 90-acre clearcut sprayed with herbicides
May 1, 1976 to April 30, 1979	Post-treatment period for complete clearcut

Table 2. Timber harvesting characteristics of Leading Ridge Watershed Two.

Characteristics	Treatments			
	Lower Slope	Middle Slope	Upper Slope and Ridge Top	Total
Area cut (acres)	21.3	27.0	42.0	90.3
Basal area (sq. ft.)	2,103	2,398	3,276	7,777
Basal area/acre cut (sq. ft.)	99	89	78	--
Volume cut (cu. ft.)	53,878	87,476	66,265	207,619
Volume/acre cut (cu. ft.)	2,529	3,240	1,578	2,299

a complete riparian cut, since all of the main stream channels on the watershed are located within its boundaries. Phase two consisted of clearcutting an additional 27.0 acres on the middle slope portion of the watershed during the winter of 1971-72. Total volume removed was 87,476 cubic feet (Table 2). Phase 3 expanded the clearcut to include the remaining portion (upper slope-ridge top) of the watershed. This 42-acre clearcut was conducted during the winter of 1975-76. Total timber volume removed was 66,265 cubic feet.

Following the completion of phase one, road areas and log loading areas were seeded with a mixture of annual and perennial ryegrass along with pulverized limestone and 10-10-10 fertilizer to facilitate rapid revegetation and reduce erosion. No seeding followed the completion of phases two or three.

During the summers of 1967, 1968, and 1969, stump sprouts in the clearcut area (lower slope) were sprayed with a mixture of 2,4,5-T and 2,4,-D herbicides (Amchem Weedone). The application rate was 2 pounds of acid equivalent per acre applied with mist-blowers.

In June 1974 the lower and middle slope portions of the watershed (Phases 1 and 2) were sprayed with herbicides to control the invasion of herbaceous vegetation and woody sprout regrowth. This treatment consisted of an aerial application of a mixture of Atrex (atrazine) and Weedone IBK (2,4-D; 2,4,5-T). In June 1977 the entire 90-acre clearcut was sprayed with herbicides. This treatment consisted of an aerial application of a mixture of Weedone BK (2,4-D; 2,4,5-T) and Hyvar XL (Bromacil) to the upper 68 acres of the clearcut. Each of the lower 22 acres received an application of Velpar (triazine).

RESULTS AND DISCUSSION

Water Quantity

Annual Water Yield

The hydrologic year used was May 1 through April 30 because correlation analysis indicated that this water year had the highest rainfall-runoff coefficient (r = 0.992). Annual prediction equations were derived by simple linear regression techniques using runoff from the control watershed (LR-1) as the independent variable.

Findings indicated that the lower slope clearcutting resulted in increases on a total watershed bases from 1.25 to 2.98 area-inches in annual water yield during the 5 years after cutting (Table 3). This represents an increase of 6.3 to 15.1 inches on an area-cut basis and is equivalent to 3.6 and 8.6 million gallons of additional water per year.

Table 3. Effects of treatments on annual and seasonal water yields. All values are in inches.

Water Year (May-April)	Water Yield Change			Precipitation Departure from 8-Year Mean		
	Growing	Dormant	Annual	Growing	Dormant	Annual
	Treatment: 21 acres clearcut on lower slope					
1967	+2.19*	-0.22	+2.01*	+6.57	-5.57	+1.00
1968	+0.88*	+0.23	+1.25*	+2.94	-4.22	-1.28
1969	+1.02*	+1.58*	+2.48*	+0.06	+2.64	+2.70
1970	+1.92*	+1.36	+2.98*	+5.83	+3.18	+9.01
1971	+1.23*	+0.94	+1.97*	+3.84	+1.30	+5.14
	Treatment: Additional 27 acres clearcut on middle slope					
1972	+0.95*	+2.82*	+3.69*	+13.44	+6.30	+19.74
1973	+1.25*	+1.98*	+3.11*	+1.46	+1.58	+3.04
	Treatment: Entire 48-acre clearcut sprayed with herbicides					
1974	+3.61*	+1.72*	+5.18*	+3.05	+3.30	+6.35
1975	+3.23*	-0.73	+2.41*	+12.56	-2.01	+10.55
	Treatment: Additional 42 acres clearcut on upper slope and ridge top					
1976	+7.25*	+0.46	+7.61*	+13.07	-1.90	+11.17
	Treatment: Entire 90-acre clearcut sprayed with herbicides					
1977	+9.63*	+0.11	+9.39*	+9.41	+3.49	+12.90
1978	+2.99*	+2.61*	+5.46*	+5.56	+5.31	+10.87

* Significant at 5 percent level of confidence.

With the exception of 1968, it becomes readily apparent from Table 3 that the increase in annual discharge during the lower slope post-treatment period has remained relatively stable at an average of 2.4 inches. This apparent stability is evident despite the fact that since 1969 evapotranspiration has increased as a result of regrowth of herbaceous and woody vegetation on the lower slope clearcut.

However, it should be noted that, since 1969, annual precipitation has been greater than the first three post-treatment years. This above "normal" 1970 and 1971 annual precipitation, with respect to the previous post-treatment years, has minimized the effects of increased evapotranspiration. That is, the increases in 1970 and 1971 annual precipitation may approximate the water loss from regrowth, thus causing the stability of increased annual discharge.

The 1972 and 1973 annual water yield increases of 3.69 and 3.11 area-inches, respectively, represent the combined effects of both the lower and middle slope clearcuts before herbiciding. These increases (8.1 and 6.9 inches on an area-cut basis) are somewhat smaller than expected from the 48-acre clearcut and reflect either extremely wet conditions (1972) and/or high evapotranspirational (ET) losses (1973). Because of tropical storm Agnes in June, 1972, saturated conditions existed on both the clearcut and control watersheds during June and the early part of July, thus reducing the potential treatment effect. Regrowth of both herbaceous and woody vegetation on both clearcuts and increased ET losses held the 1973 yield increase to 3.11 area-inches. This is particularly evident when the 1973 increase is compared to the 1974 increase of 5.18 inches (11.4 inches on an area-cut basis) (Table 3). This increased flow followed the aerial application of herbicides to the entire 48-acre clearcut. The herbicide application resulted in almost a 100 percent elimination of both herbaceous and woody vegetation on the clearcut. The 1975 increase of 2.41 area-inches was considerably lower than expected and appeared to reflect a combination of increasing ET due to regrowth and saturated conditions on both the clearcut and forested watersheds. Annual precipitation in 1975 was 10.55 inches above normal; growing season precipitation was 12.56 inches above normal.

The 1976 yield increase of 7.61 inches (Table 3) reflects the combined effects of the lower and middle slope clearcuts as well as an additional 42-acre clearcut on the upper slope and ridge top. The application of herbicides to the entire 90-acre clearcut increased the yield in 1977 to 9.39 inches. Rapid revegetation reduced this increase to 5.46 inches in 1978. The 1977 increase is equivalent to approximately 27 million gallons of additional water per year. The 9.39-inch increase is well within the range of those experienced by other such experiments in the East and in fact may be somewhat less than the maximum potential increase because of the extremely wet conditions of the last 3 years. Rainfall since 1976 has averaged close to 11.6 inches above normal.

Seasonal Water Yield

For analyzing the treatment effect on seasonal water yields, May 1 through October 31 was selected as the growing season and November 1 through April 30 as the dormant season. Seasonal prediction equations were derived by linear regression, using runoff from the control watershed as the independent variable.

The effect of clearcutting the lower slope on the growing season water yields for 1967 through 1971 is shown in Table 3. Significant increases were measured during each growing season of the phase-one post-treatment period. These increases ranged from 0.88 to 2.19 area-inches (4.4 to 11.1 inches on the area-cut basis) and were a direct result of decreased evapotranspiration and canopy interception. However, the distribution and amount of rainfall appeared to exert a strong influence on the magnitude of these increases. With the exception of 1968, the growing seasons with above-normal rainfall were also the growing seasons with the greatest response to treatment. When precipitation was near normal, as was the 1969 growing season, a considerably smaller increase occurred. The smallest increase in water yield, 0.88 area-inch, occurred during the 1968 growing season. Although precipitation during this period was 2.9 inches above normal, virtually all this increase fell during May and consequently had little effect on the overall 1968 growing season water yield increase.

Water yield increases for the 1972 through 1975 growing seasons reflect the combined effects of both the phase one and phase two clearcuttings. The 1972 yield increase of 0.95 inch was much lower than expected. Here, as was discussed earlier, the effects of tropical storm Agnes on the magnitude of the independent variable used in the prediction equation become apparent. Precipitation during the 1972 growing season was 32.4 inches, 13.4 inches above normal. Streamflows from the treated and control watersheds were 20.71 and 16.82 area-inches, 17.6 and 14.0 inches, respectively above the calibration period mean. Since these values greatly exceeded any of the calibration data used in developing the prediction equation, the reliability of the statistical techniques used to determine the treatment effect and its significance become greatly reduced. Furthermore, water yield increases occurred primarily during the growing season or recharge periods when a moisture-storage differential exists between the clearcut and forested areas. Because of the extreme rainfall during the 1972 growing season, saturated conditions existed on both treated and control watersheds, minimizing the effects of the timber harvest.

The 1973 growing season yield of 1.25 inches was also much lower than expected and reflects the increased ET losses as a result of regrowth on the cut-over area. This fact was verified by increases in water yield in 1974 and 1975 of 3.61 and 3.23 inches following the elimination of regrowth with herbicides.

Increasing the clearcut to 90 acres in 1976 resulted in a growing season yield of 7.25 inches. This increased to 9.63 inches in 1977 following the aerial application of herbicides. A substantial reduction in increased discharge occurred in 1978. This reduction (6.64 inches) was considerably more than anticipated and can only be partially attributable to increased evapotranspiration due to revegetation. Although growing season precipitation was 5.56 inches above pretreatment levels, virtually the entire increase occurred in May and early June when treatment effects are minimal due to high moisture conditions on both forested and clearcut areas. Consequently, the distribution of precipitation may have contributed to lowering the increased yield.

Treatment had a variable effect on dormant season water yields as shown in Table 3. Insignificant decreases in stream discharge occurred in 1967 and 1975; increases were measured in the remaining 10 years. Of these, only the 1969, 1972, 1973, 1974 and 1978 water years were significant. These increases ranged from 1.58 in 1969 (lower slope cut) to 2.82 inches in 1972 (lower and middle slope cut).

The increases in water yield during the dormant season reflect the effects of treatment on soil moisture recharge during the early fall months and possibly on snow accumulation and melt. However, the magnitude of the treatment effect on the dormant season discharge also reflects the amount of precipitation. Decreases in water yield in 1967 and 1975 were associated with below-normal precipitation. Conversely, the significant increases in water yield during the dormant season were associated with above-normal precipitation and substantial snow accumulation (e.g., 1969, 1972, and 1978).

Monthly Water Yield

Regression equations developed from the calibration period were used to predict monthly water yield for Watershed Two for all post-treatment periods. Changes in streamflow as a result of phase one for May 1967 through April 1971 are presented in Table 4. The magnitude in increased flow varied considerably. Significant increases after phase one ranged from a high in August 1967 of 0.66 area-inch to 0.07 area-inch during July 1968. The range in significant increases from the combined effects of phase one and phase two was from 1.15 area-inches in June 1972 to 0.10 area-inch in September 1972. The high increase in June 1972 is a direct result of tropical storm Agnes. Monthly increases from the combined 90-acre clearcut ranged from 3.1 inches in July 1977 to 0.26 inch in September 1978. Comparision of the 1974 and 1977 monthly increases with the preceeding year clearly shows the impact of the herbicide treatments on streamflow. In almost all cases, the monthly flows following treatment were higher than the preceeding year's value. For example, the yield increase in July 1976 was 0.59 inch; following the herbicide treatment the yield increase for July 1977 was 3.10 inches.

Table 4. Effects of treatments on monthly streamflow from May 1967 through April 1979.[1] All values are in inches.

Water Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1967	0.099	0.275*	0.388*	0.660*	0.287*	-0.131	-0.353*	-0.207	-.118	-0.024	-0.105	-0.094
1968	0.342*	0.291*	0.066*	0.041	0.111*	0.211*	0.236*	-0.229*	-.102	-0.088	-0.135	-0.034
1969	0.036	0.192*	0.345*	0.285*	0.031	0.068*	0.324*	0.204*	0.118	0.377*	0.439*	0.204
1970	0.158	0.208*	0.423*	0.283*	0.116*	0.653*	-0.382*	0.068	0.109	0.326*	0.186	0.045
1971	0.218	0.194*	0.169*	0.147*	0.246*	0.233*	0.165*	0.058	0.115	0.293*	-0.001	0.199
1972	0.266*	1.148*	0.080	0.126*	0.103*	0.207*	1.059*	0.412*	0.045	0.226*	0.187	0.410*
1973	0.348*	0.342*	0.174*	0.093	0.112*	0.287*	0.377*	0.585*	0.246	0.064	0.044	0.414*
1974	0.157	1.130*	0.695*	0.361*	1.092*	0.290*	0.568*	0.594*	0.048	-0.005	0.086	0.203
1975	0.368*	1.024*	0.446*	0.360*	-0.509	-0.212	-0.392*	-0.019	0.042	-0.859*	-0.195	0.027
1976	0.660*	1.721*	0.593*	1.764*	0.769*	0.477	0.001	-0.055	-0.042	0.129	0.269	0.093
1977	0.131	0.530*	3.105*	1.257*	2.322*	0.638	-0.634*	0.078	-0.190	-0.024	0.281	-0.368*
1978	0.558	0.725*	1.083*	0.586*	0.262*	0.187*	0.291*	1.167*	1.267*	0.495*	-0.127	-0.246

[1] See Table 1 for specific treatment periods.

*Significant at 5 percent.

A rather consistent pattern in the timing of these increases in streamflow is evident for all post-treatment periods. In general, significant increases in water yield occurred primarily during the months May through November and resulted from decreased evapotranspiration, increased soil moisture, and elimination of canopy interception. Significant increases in water yield during the dormant season months resulted from the higher soil moisture content on the treated watershed as compared to the control watershed as well as reduced interception loss. Because of this, less precipitation was needed to recharge the soil reservoir on the treated watershed, leaving more available for streamflow. Increases in stream discharge that occured after the soil reservoir was recharged on both treated and control watersheds were due to the effect of treatment on snow accumulation, melt, and timing of melt runoff.

Low Flow

The number of days per year in which stream discharge was below 0.1 csm[1/] (100 gallons per acre per day) was used to determine the effect of treatment on low flows. Analysis of variance and regression analysis were used to determine the significance of change.

On the treated watershed, the number of days that flow was below 0.1 csm decreased from an average of 161 days per year during the calibration period to an average of 47 days per year during the five post-treatment years following the lower slope cutting (Table 5). At the same time, the number of days with flow below 0.1 csm on the control watershed decreased from an average of 175 days to 114 days. Similar decreases were observed following the additional 27-acre clearcut on the middle slope portion of the watershed. Since 1974, following the herbicide application, the average number of days per year in which streamflow was below 0.1 csm was 1 on the treated watershed and 91 days on the forested control. In 1974, 1976 and 1978 streamflow did not drop below 0.1 csm on the treated watershed.

The effect of the above-normal precipitation during the growing season (Table 3) resulted in the decrease in the number of days with low flow on the control watershed and also accounted for part of the decrease on the treated watershed. Although analysis of variance indicated that no significant difference existed between the two watersheds before cutting, it was not certain what effects the treatments alone had on the significant reduction in the number of days with low flow. Therefore, regression analysis was used to determine the treatment effect. The results indicate that treatment alone resulted in significant reductions in the number of days of low flow for nine of the 12 post-treatment years. The significant reductions of low flow days ranged from 33 in 1967 to 114 in 1978. The average reduction during the entire 12-year post-treatment period was 45 days per year.

1/ csm = cubic feet per second per square mile.

Table 5. Comparison of the number of days per year that streamflow was below 0.1 csm.

Period	Measured		Predicted Treated Watershed	Difference
	Control Watershed	Treated Watershed		
Calibration period mean	175	161	-	-
Treatment: 21 acres clearcut on lower slope				
1967	87	16	48	-33*
1968	115	81	84	- 3
1969	158	79	139	-60*
1970	99	20	64	-41*
1971	113	42	81	-39*
Mean	114	47	83	-36*
Treatment: Additional 27 acres clearcut on middle slope				
1972	101	17	66	-49*
1973	133	57	107	-50*
Mean	117	37	86	-49*
Treatment: Entire 48-acre clearcut sprayed with herbicides				
1974	116	0	85	-85*
1975	47	4	8	- 4
Mean	82	2	42	-45*
Treatments: Additional 42 acres clearcut on upper slope and ridge top. Entire 90-acre clearcut sprayed with herbicides.				
1976	53	0	4	- 4
1977	100	1	64	-63*
1978	139	0	114	-114*
Mean	97	0	61	-61*
Overall post-treatment mean	105	26	71	-45*

* Significant at 5 percent.

The effect of treatment on the number of low flow days in 1975 and 1976 (Table 5) was obviously greater than the results indicated and was confounded by the analytical techniques used in assessing the changes. Problems arose using regression analysis when post-treatment data on the control watershed fell outside the range of values collected during the calibration period. In this case the number of days of low flow on the control watershed in 1975 and 1976 were considerably below the calibration period mean of 175 days. Consequently, the predicted values on the treated watershed were much lower than would have occurred if the area had not been treated.

Flow Duration

Flow duration analysis based on mean daily flow in csm was used to show the treatment effect on various discharge classes following completion of each phase of this three-phase treatment. From the calibration data, prediction equations were computed for selected flow classes for the growing, dormant, and annual periods. These equations were then used to predict flow duration curves for the treated watershed for each season during the post-treatment periods. Flow duration curves on both the treated and control watersheds were also devėloped for the growing season (Figure 5), the dormant season (Figure 6), and annual water year (Figure 7) using calibration period data. These figures show clearly that the streamflow regimes on both watersheds were very similar prior to cutting.

Growing season predicted and measured flow duration curves for the clearcut watershed following the lower slope, middle slope, and upper slope and ridge top clearcuts are shown in Figures 8, 9, and 10 respectively. The measured flow duration curves, are above and to the right of the predicted curves for almost all flow classes and reflect the effects of the individual treatments. In general, there was considerable augmentation of the low and medium flow classes (flows below 0.4 csm) and relatively smaller increases in higher flows following the lower slope clearcut (Figure 8). This augmentation was more dramatic following the middle slope cutting (Figure 9) particularly for the flow classes between 0.4 and 2.0 csm. Clear-cutting the upper slope and ridge top of the watershed further augmented the median growing season discharge classes (flows between 1.0 and 4.0 csm) (Figure 10). The frequency of flows above the 4.0 csm discharge class were also increased during the phase three post-treatment period.

The effects of the lower slope (Figure 11), middle slope (Figure 12), and the upper slope and ridge top (Figure 13) treatments on the dormant season flow duration curves were very indicative of dormant season water yield changes in Table 3. The lower slope cutting had little, if any, effect on discharge classes above 0.7 csm; below 0.7 csm, minor increases in the flow regime did occur. This variable response was similar to the variable dormant season water yield changes. In contrast, the measured dormant season flow duration curve was above the predicted curve for all flow classes during the middle slope post-treatment period. The flow classes showing the greatest increase in frequency occurred between 0.7 and 3.0 csm. Following completion of the upper slope and ridge top treatment, the frequency of flows above specific discharge classes followed a pattern similar to that observed

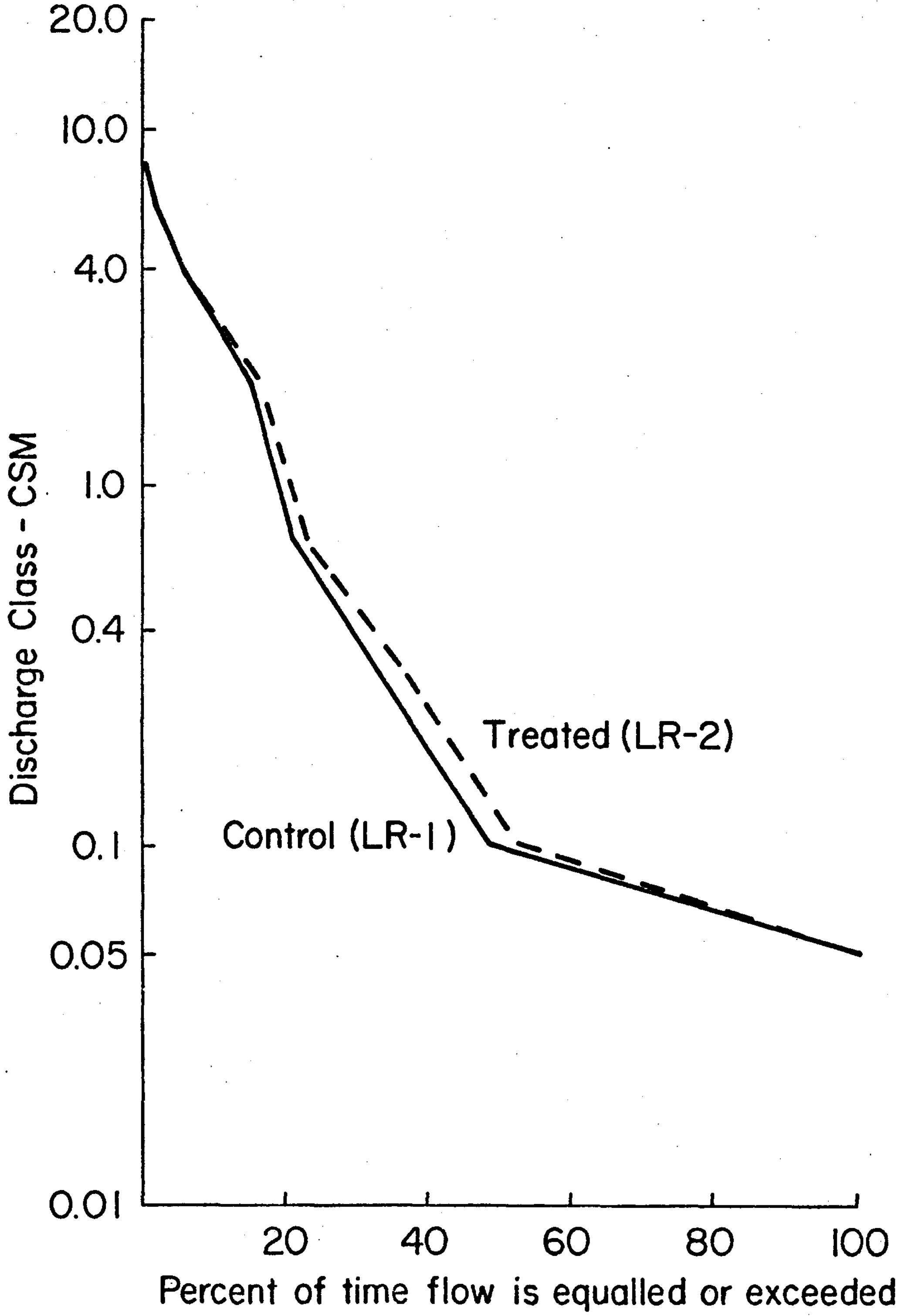


Figure 5. Growing season flow duration curves for the control and treated watersheds during the calibration period.

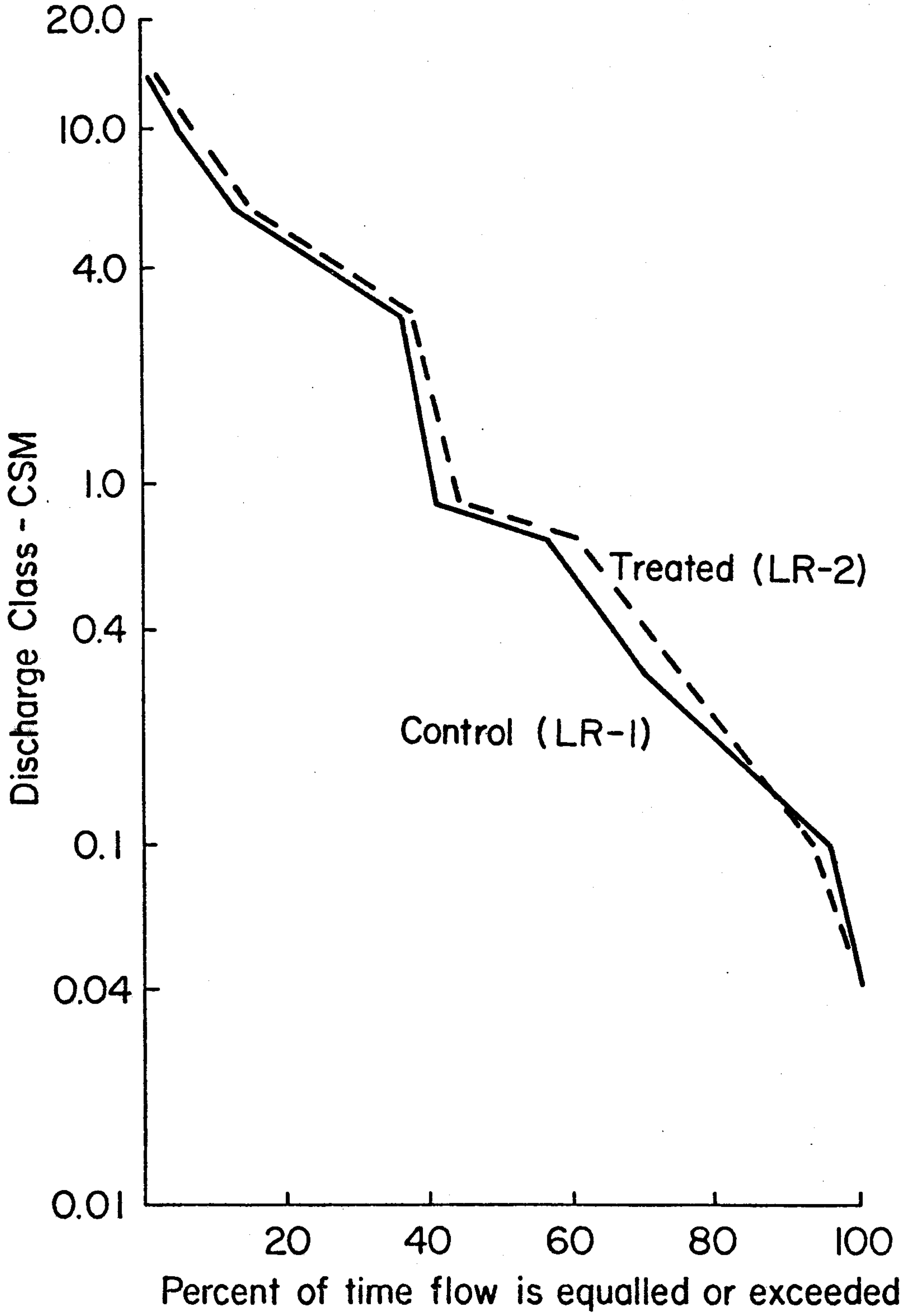


Figure 6. Dormant season flow duration curves for the control and treated watersheds during the calibration period.

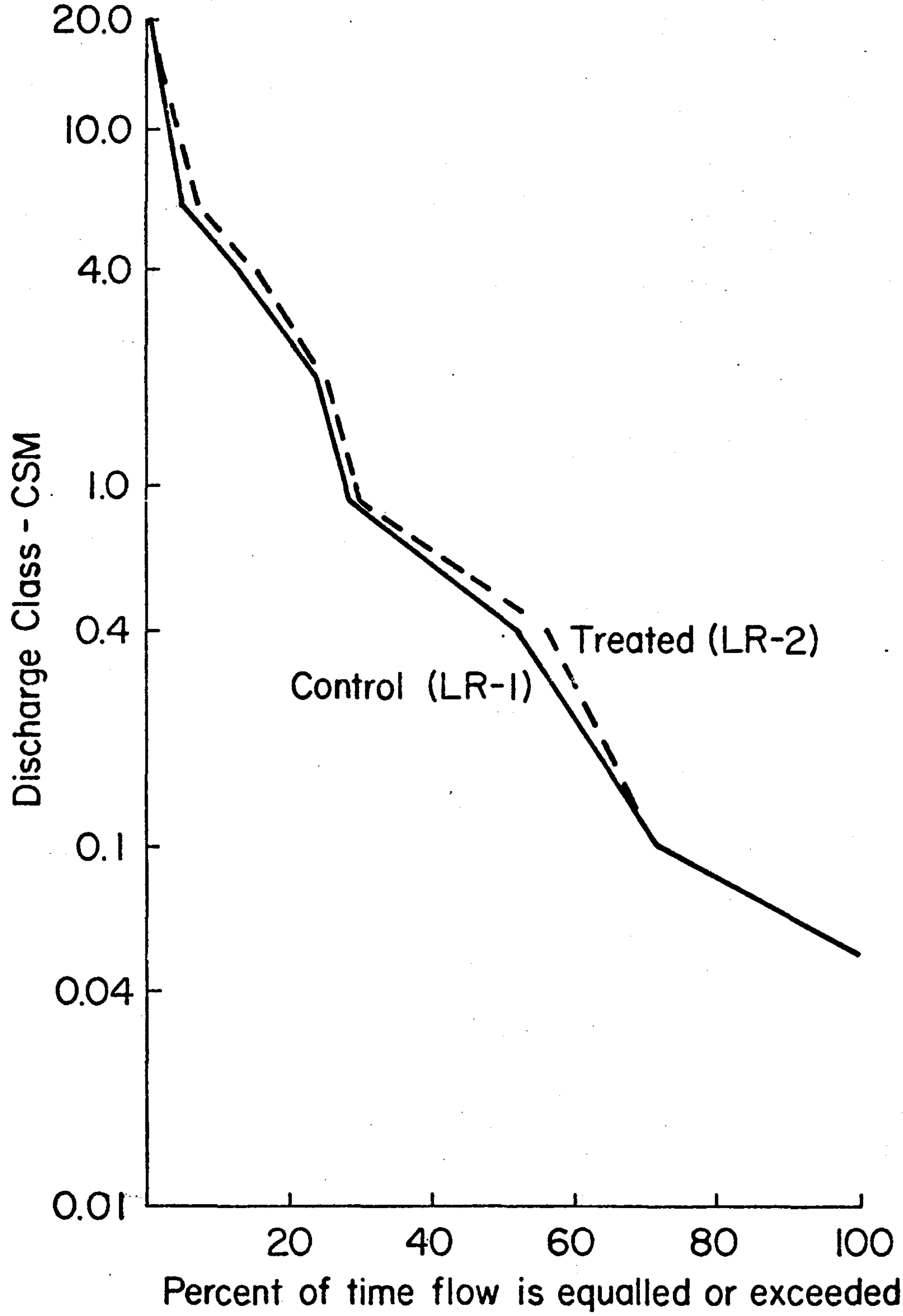


Figure 7. Annual flow duration curves for the control and treated watersheds during the calibration period.

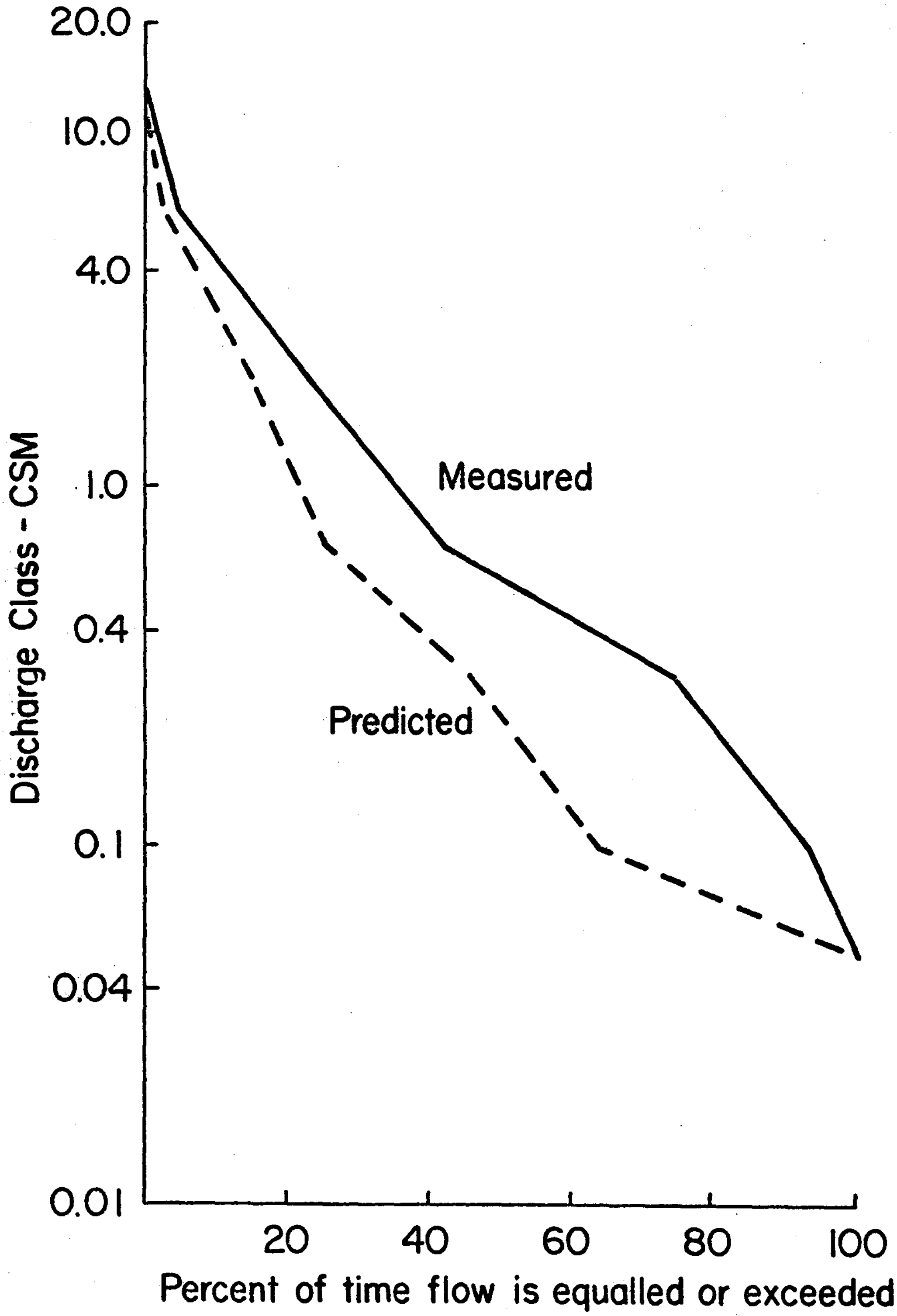


Figure 8. Predicted and measured growing season flow duration curves for the treated watershed during the lower slope post-treatment period (May 1, 1967 through October 31, 1971).

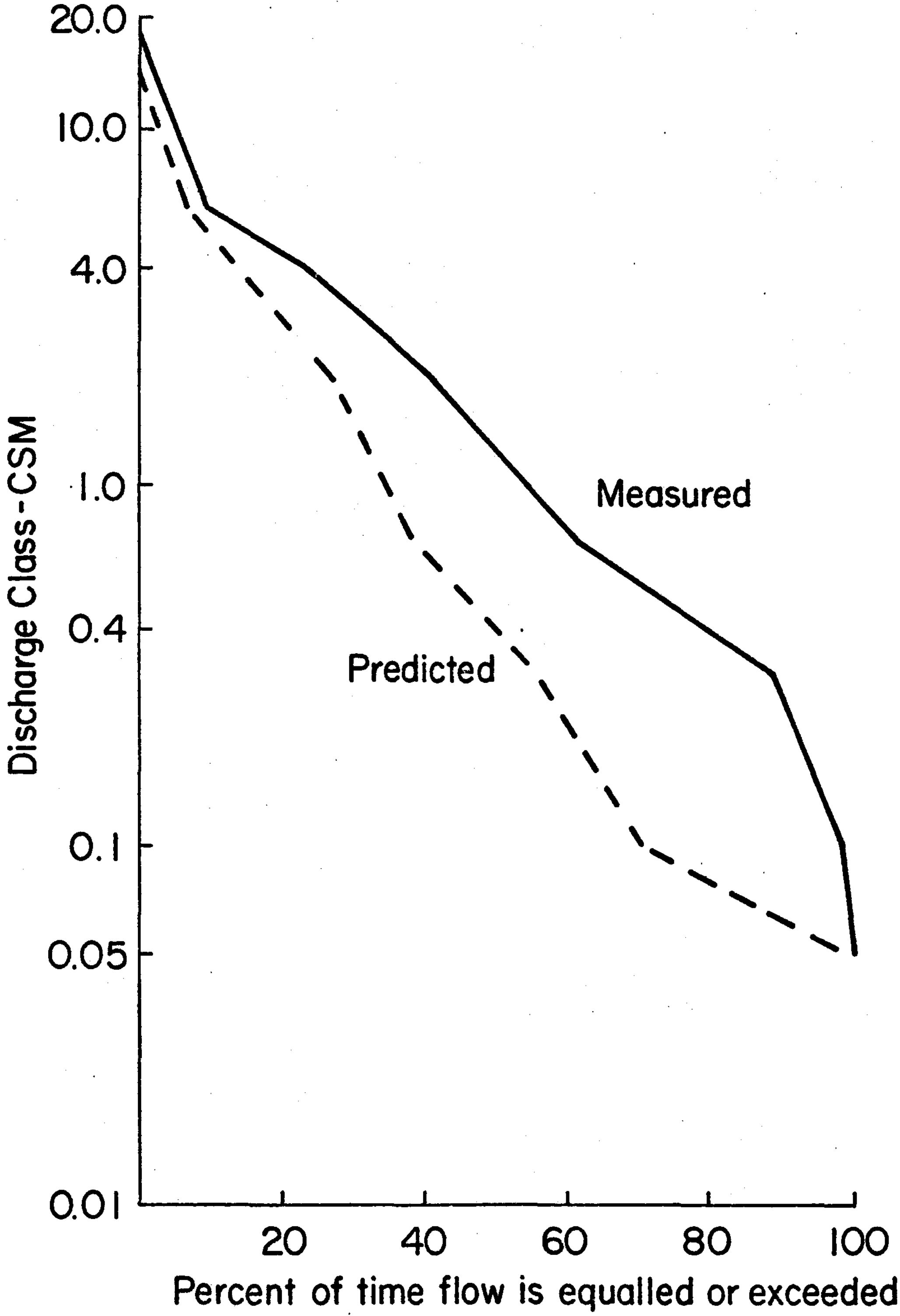


Figure 9. Predicted and measured growing season flow duration curves for the treated watershed during the upper slope and ridge top post-treatment period (May 1, 1976 through October 31 , 1978).

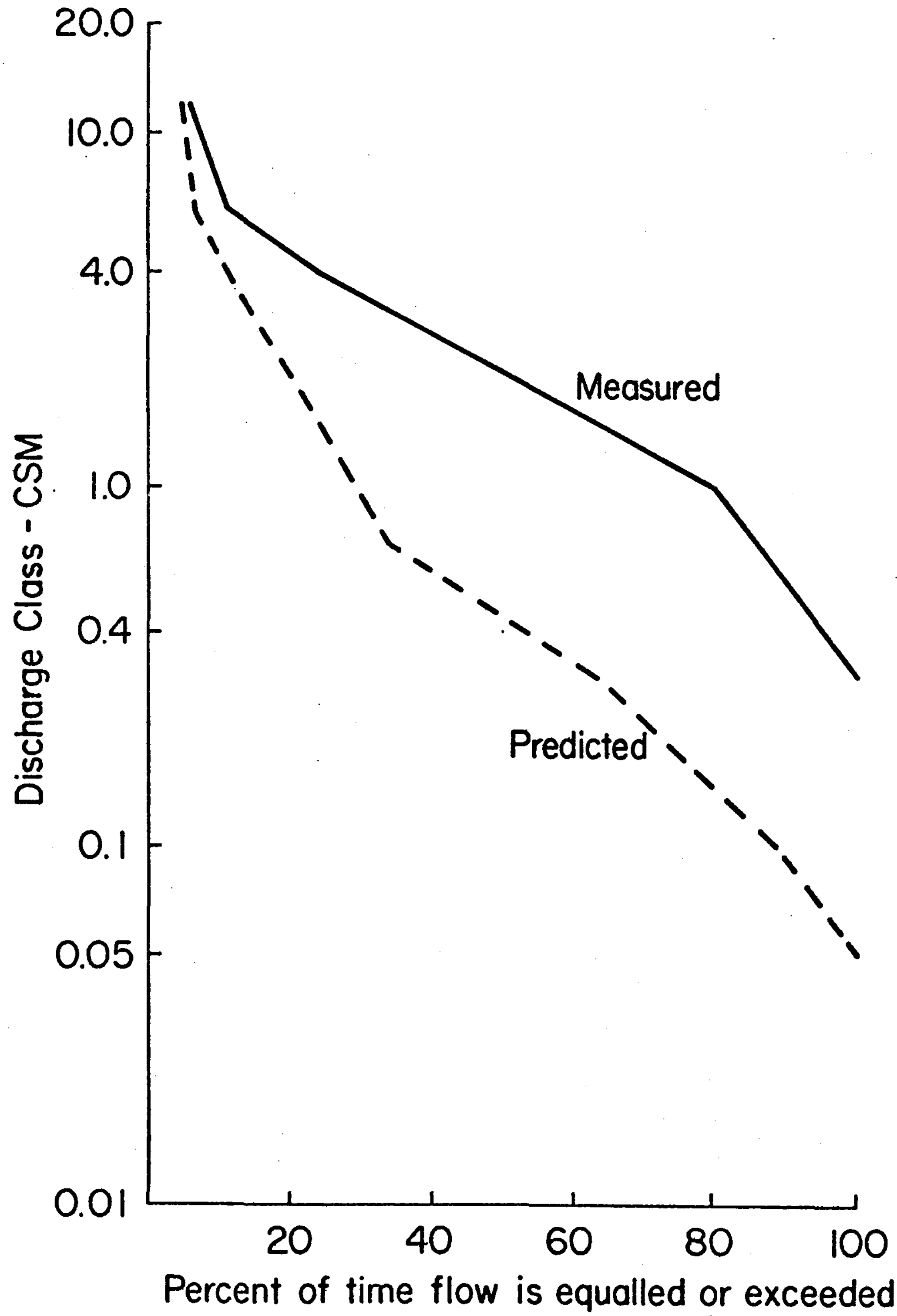


Figure 10. Predicted and measured gowing season flow duration curves for the treated watershed during the upper slope and ridge top post-treatment period (May 1, 1976 through October 31, 1978).

following the lower slope cutting. Increases in stream discharge were non-significant for 2 of the 3 years in this post-treatment period (Table 3).

Predicted and measured annual flow duration curves for each phase of this three-phase experiment are shown in Figures 14, 15 and 16. Changes in these flow duration curves followed a pattern similar to the growing season curves. Increases in the frequency and magnitude of the discharge classes increased as the size of the clearcut increased. Flow classes below 0.4 csm were most affected by the lower slope cutting (Figure 14). Augmentation of flows below 1.0 csm was evident during the middle slope post-treatment (Figure 15), while flow classes as high as 6 csm were increased during the upper slope and ridge top post-treatment period (Figure 16).

Runoff as a Percent of Precipitation

The effects of clearcutting on runoff as a percent of precipitation for the growing seasons and annual water years during each post-treatment period are shown in Table 6. Using regression analysis to determine treatment effect, significant increases in runoff as a percent of precipitation for 1967 through 1978 for both the growing season and annual water years were observed. Significant increases during the growing season ranged from 4.6 percent in 1968 to 34.8 percent in 1977. On an annual basis, significant increases ranged from 3.3 percent in 1968 to 19.0 percent in 1977. In all cases, significant increases in runoff as a percent of precipitation corresponded to significant increases in stream discharge.

It is interesting to note that prior to cutting approximately 37 percent of the annual rainfall occurred as streamflow; after cutting, an average of 57 percent was converted to streamflow. The highest percentage of rainfall to occur as runoff (73 percent) occurred in 1977, a doubling of the efficiency of the watershed in coverting rainfall into runoff.

Summer Maximum Peakflows

The effects of the various treatments on maximum peakflows were also analyzed. Since clearcutting has the greatest effect on summer and early fall flows, only those storms occurring during June through October were analyzed. Storm peaks were sub-divided into 3 classes (0-1 csm, 1-4 csm, and >4 csm) and prediction equations developed using standard linear regression techniques.

Progressively increasing the size of the clearcut on LR-2 resulted in progressively larger increases in all three classes of summer peakflows the first year following each cutting. The 24 storms occurring the first summer (1967) after the lower slope cutting (Table 7) had an average increase in peakflow of 344 percent

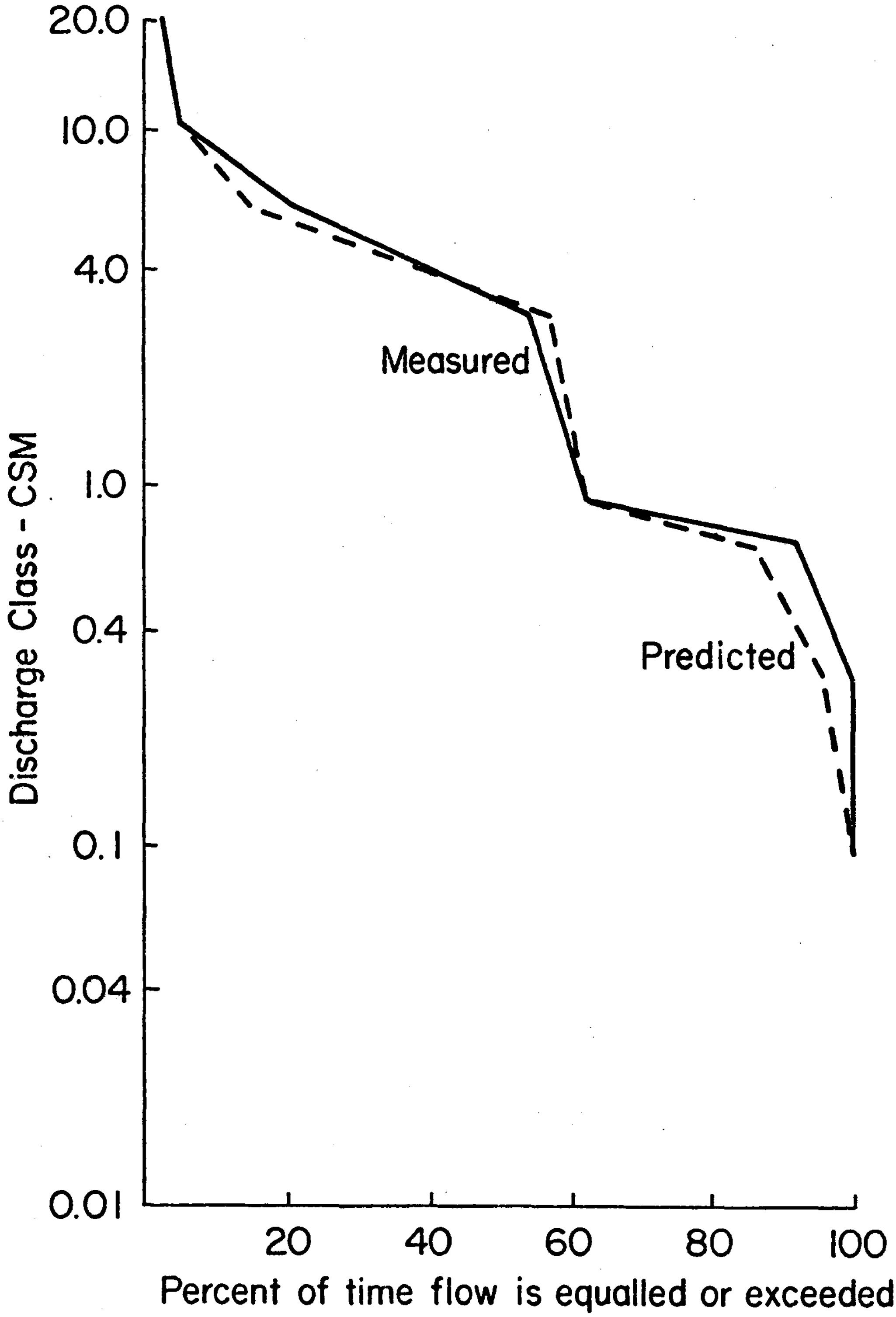


Figure 11. Predicted and measured dormant season flow duration curves for the treated watershed during the lower slope post-treatment period (November 1, 1967 through April 30, 1971).

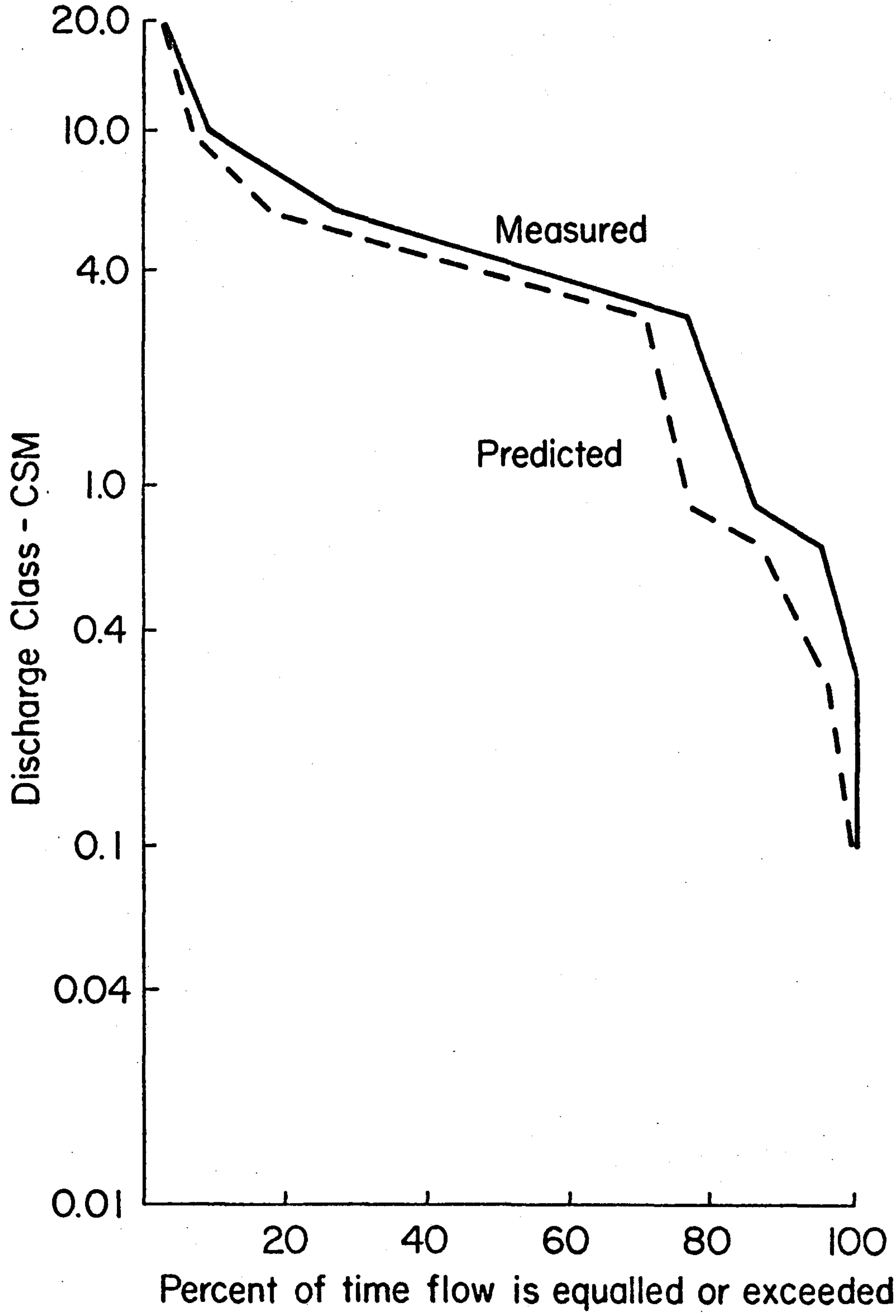


Figure 12. Predicted and measured dormant season flow duration durves for the treated watershed during the middle slope post-treatment period (November 1, 1972 through April 30, 1975).

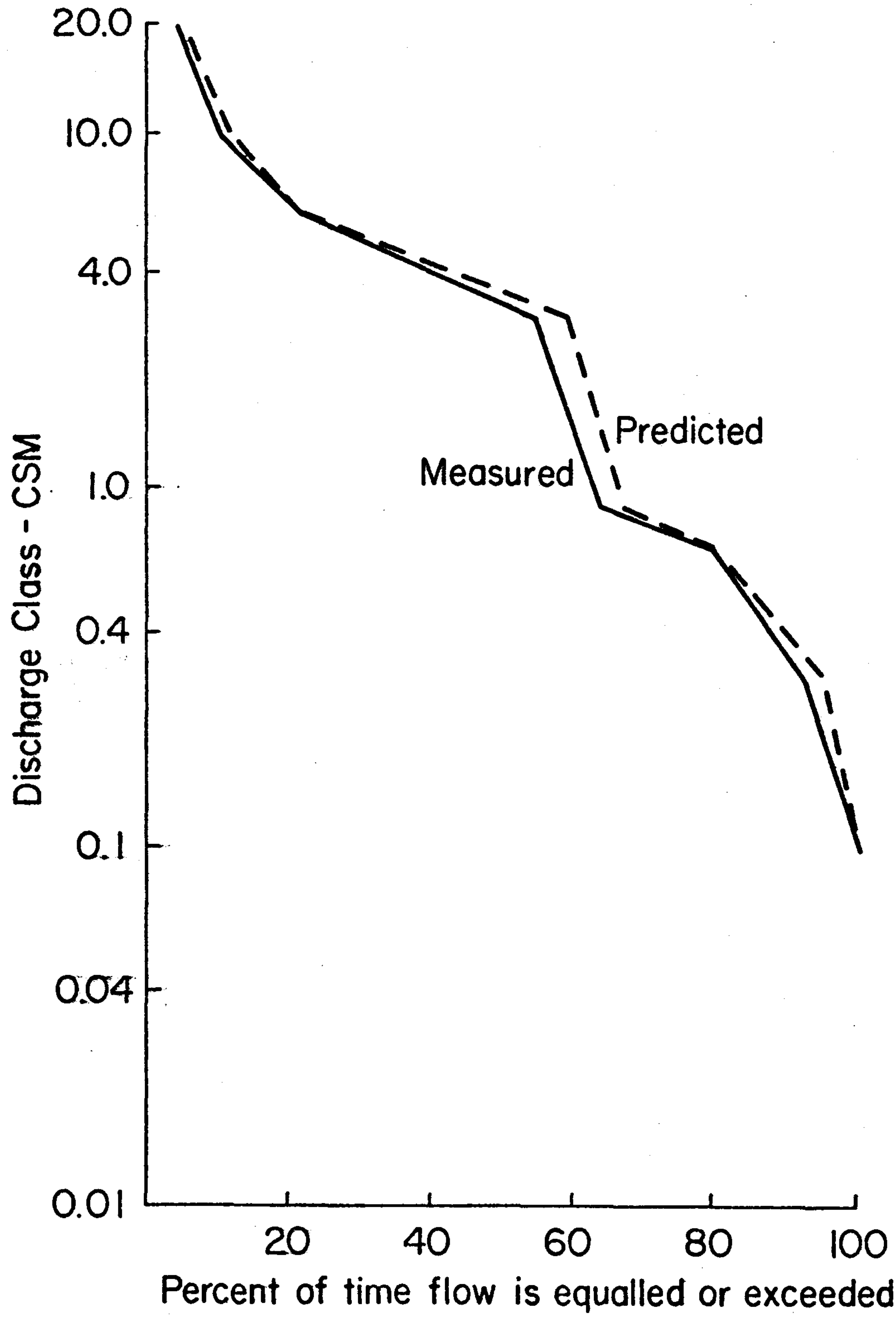


Figure 13. Predicted and measured dormant season flow duration curves for treated watershed during upper slope and ridge top post-treatment period (November 1, 1976 through April 30, 1979).

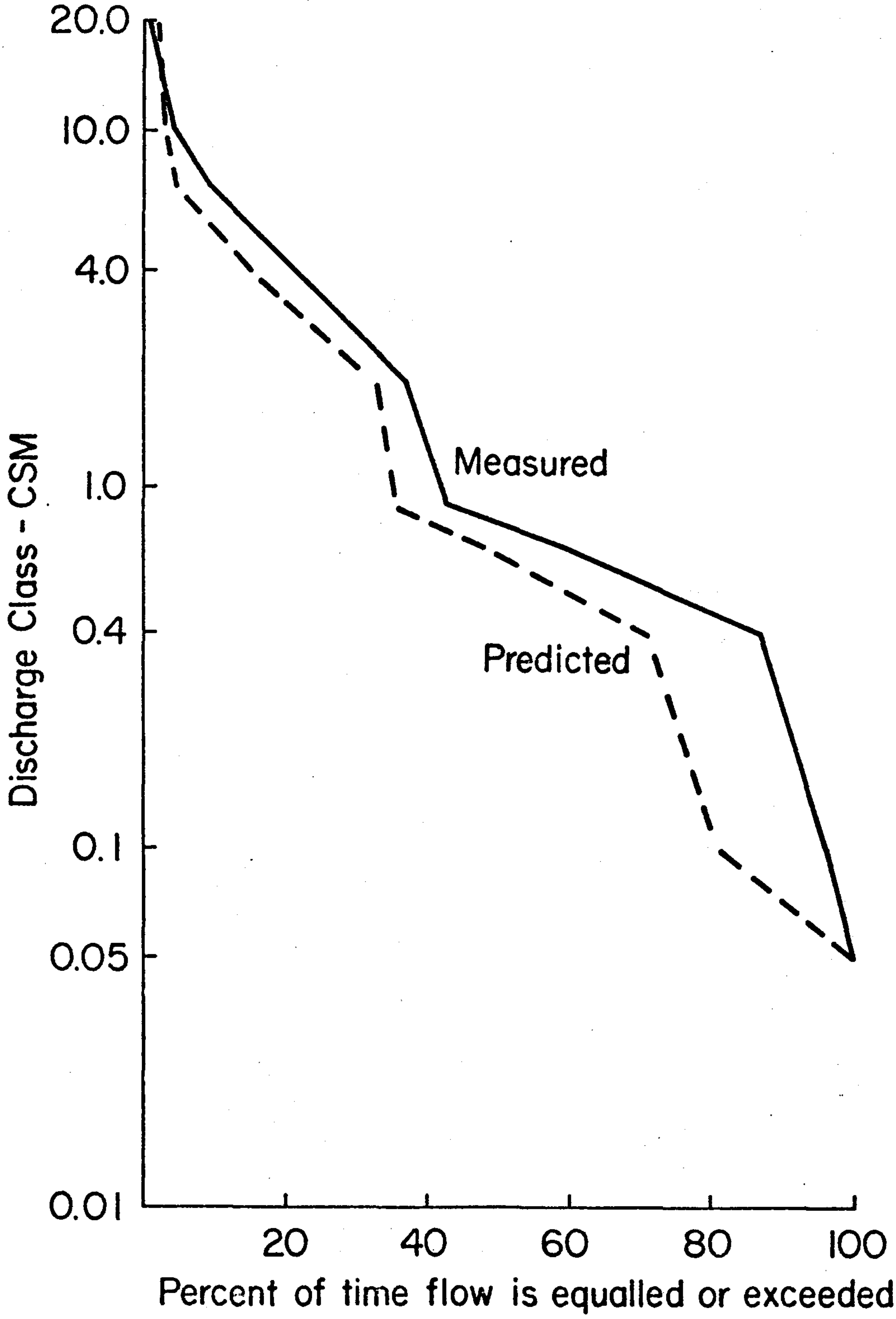


Figure 14. Predicted and measured annual flow duration curves for the treated watershed during the lower slope post-treatment period (May 1, 1967 through April 30, 1971).

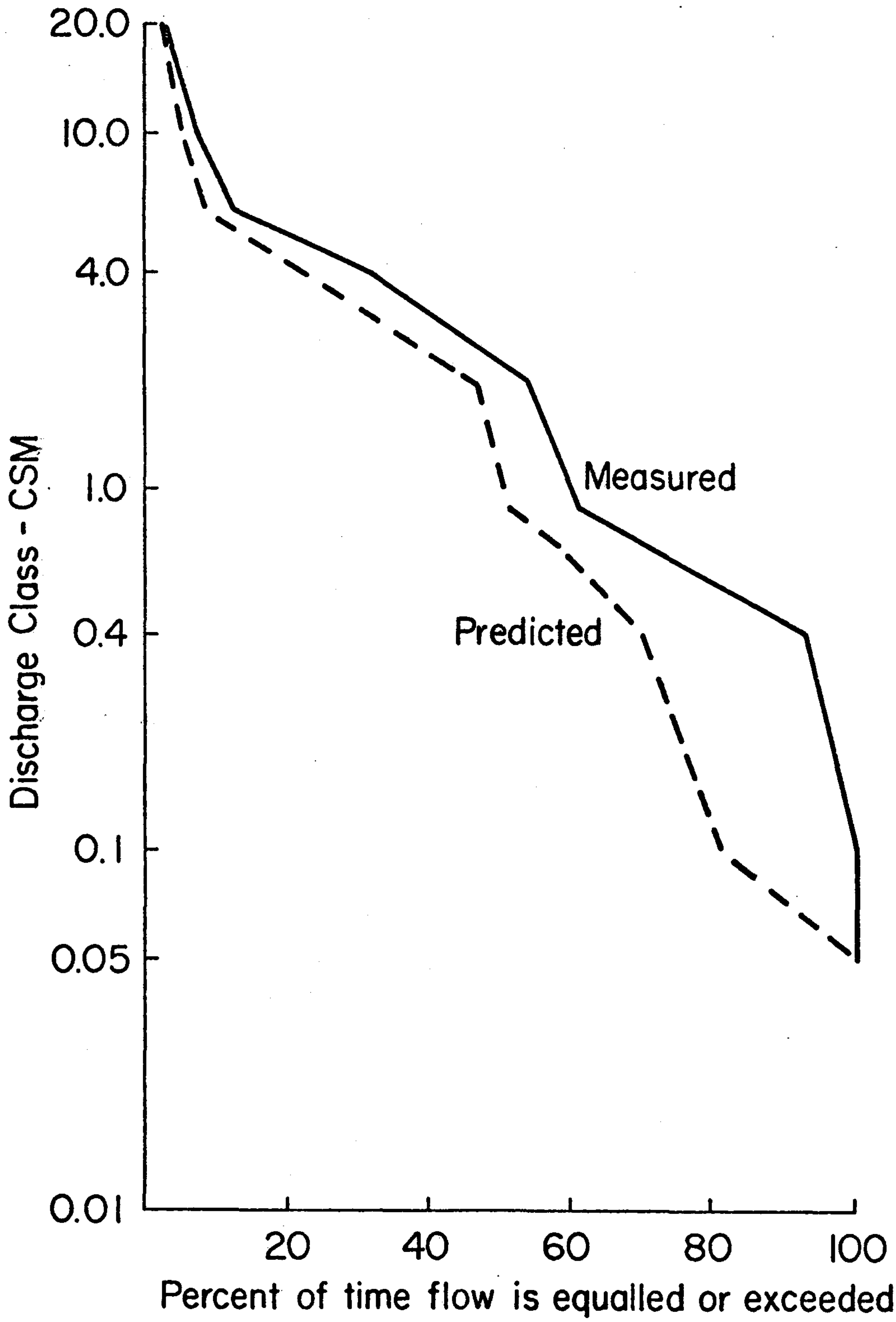


Figure 15. Predicted and measured annual flow duration curves for the treated watershed during the middle slope post-treatment period (May 1, 1972 through April 30, 1979).

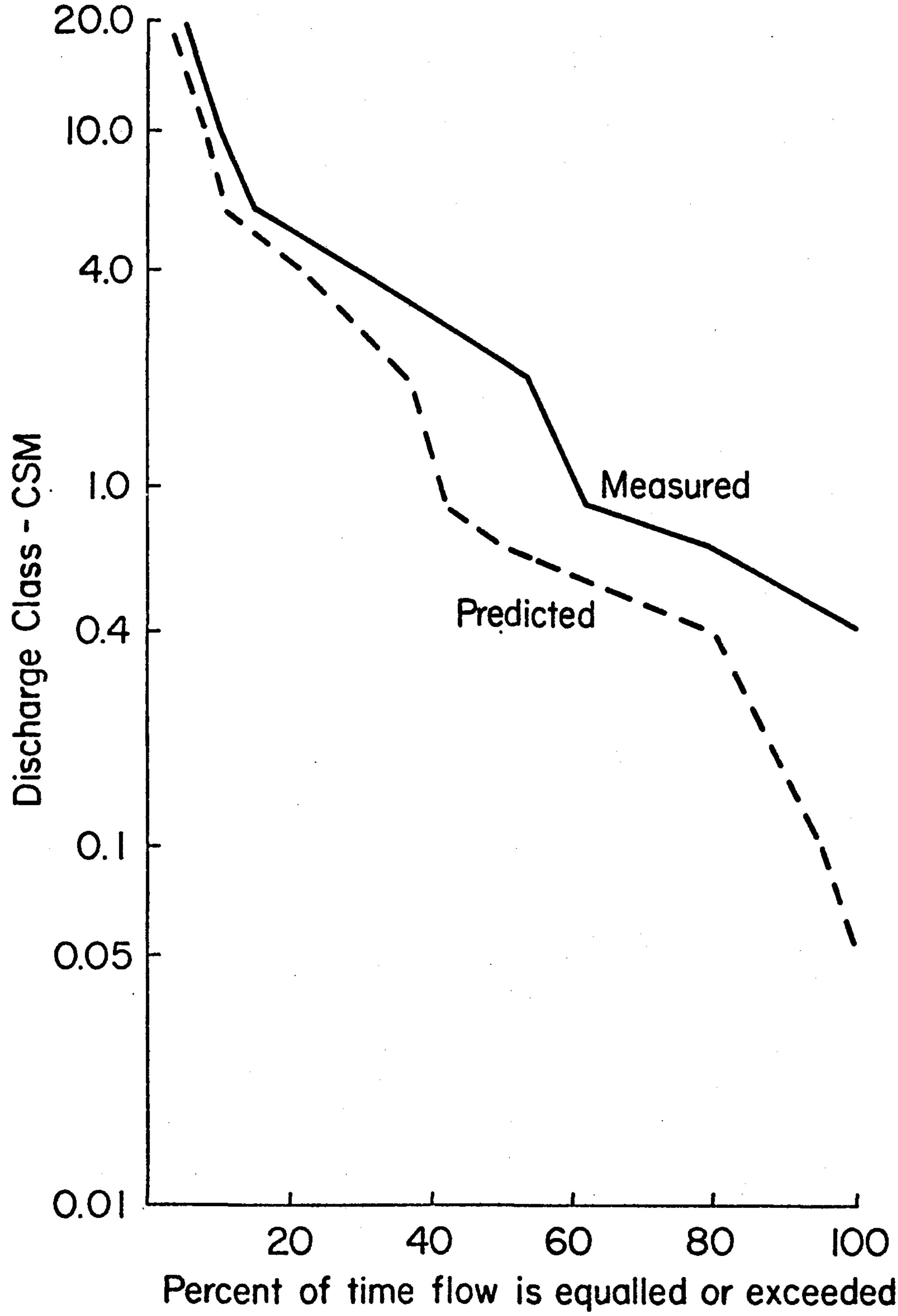


Figure 16. Predicted and measured annual flow duration curves for the treated watershed during the upper slope and ridge top post-treatment period (May 1, 1976 through April 30, 1979).

Table 6. Effects of treatments on runoff as a percent of precipitation.

Water Year	Growing Season			Annual		
	Predicted	Measured	Difference	Predicted	Measured	Difference
	Treatment: 21 acres clearcut on lower slope					
1967	25.8	35.3	+ 9.5*	45.5	50.5	+ 5.0*
1968	20.7	25.3	+ 4.6*	33.8	37.1	+ 3.3*
1969	9.0	14.4	+ 5.4*	40.1	46.3	+ 6.2*
1970	10.0	18.2	+ 8.2*	48.1	54.9	+ 6.7*
1971	14.5	20.4	+ 5.9*	47.7	52.4	+ 4.7
	Treatment: Additional 27 acres clearcut on middle slope					
1972	58.8	64.0	+ 5.2*	65.4	72.1	+ 6.7*
1973	17.5	24.1	+ 6.6*	45.8	53.5	+ 7.7*
	Treatment: Entire 48-acre clearcut sprayed with herbicides					
1974	22.1	39.2	+17.1*	48.3	60.4	+12.1*
1975	32.1	43.8	+11.7*	54.8	59.9	+ 5.1*
	Treatment: Additional 42 acres clearcut on upper slope and ridge top					
1976	26.1	50.0	+23.9*	49.7	65.7	+16.0*
	Treatment: Entire 90-acre clearcut sprayed with herbicides					
1977	16.9	51.7	+34.8*	54.0	73.0	+19.0*
1978	35.2	48.7	13.5*	53.6	65.1	+11.5*

* Significant at 5 percent level of confidence.

Table 7. Effects on summer peakflows after clearcutting 21 acres on the lower slope of Leading Ridge Two.

Date	Measured Peakflows: Control Watershed	Measured Peakflows: Clearcut Watershed	Predicted Peakflow Clearcut Watershed	Increase in Peakflow: Volume	Increase in Peakflow: Percent
	csm	csm	csm	csm	%
6/9/67	0.42	0.66	0.55	0.11	20
6/16	1.63	13.40	2.28	11.12	488
6/17	0.34	1.29	0.45	0.84	189
6/29	0.09	0.30	0.12	0.18	150
7/2	0.10	0.27	0.13	0.14	101
7/10	0.04	0.22	0.06	0.16	293
7/11	0.08	0.27	0.11	0.16	150
7/13	0.07	0.25	0.10	0.15	163
7/15	0.19	1.44	0.25	1.19	474
7/20	0.10	0.78	0.13	0.65	482
7/23	8.51	128.07	9.04	119.03	1317
8/3	1.34	10.04	1.94	8.10	418
8/4	12.07	22.18	12.96	9.22	71
8/9	0.82	5.15	1.07	4.08	381
8/20	0.50	2.81	0.65	2.16	330
8/25	0.23	1.11	0.30	0.81	266
8/27	2.01	19.90	2.72	17.18	631
8/31	0.12	0.56	0.16	0.40	250
9/21	0.06	0.29	0.08	0.21	254
9/28	16.46	104.15	17.79	86.36	485
10/5	0.08	0.30	0.11	0.19	173
10/9	0.08	0.34	0.11	0.23	209
10/14	0.12	0.52	0.16	0.36	225
10/18	0.74	8.11	0.97	7.14	736
		No. of storms		24	24
		Average Increase		11.26	344

or 11.3 csm. Following the herbiciding of the lower and middle slope clearcut (1974), the summer peakflows increased 489 percent (5.8 csm, Table 8). The most dramatic increase occurred following the herbiciding of the entire 90-acre clearcut (Table 9). In 1977, summer peakflows increased 882 percent, 14.6 csm. Increases as high as 1883 percent were measured (7/21/77). The largest rate increase, 107.3 csm, occurred on September 26, 1977. One-hundredfold increases in peak discharge occurred for 12 of the 26 storms monitored in 1977. Peakflow increases of 100-fold were also measured following the lower slope cutting and the herbiciding of the lower and middle slope clearcuts.

The overall response of the summer maximum peakflows to the clearcut-herbicide treatments are illustrated in Figures 17 and 18. Figure 17 shows the relationship between the treated and control watersheds during the calibration period for the percent of time summer maximum peakflow rates were equalled or exceeded. As is evident, the peakflow rates for both watersheds were very similar during the calibration period, with the control watershed producing slightly lower peakflows below the discharge class of 2 csm and slightly higher peakflows above 2 csm. However, this relationship has been altered as a result of clearcutting (Figure 18). Summer peakflows on the treated watershed following clearcutting and herbiciding 90 acres of this watershed were consistently higher for all discharge classes than on the forested control. The most pronounced change occurred for the low to medium size storm peakflows.

Water Quality

Stream Temperature

On the Leading Ridge Watersheds, streamwater temperature has been monitored since 1973 using Rustrak continuous temperature recorders. U-shaped maximum and minimum thermometers were used prior to 1973. These thermometers were read and reset weekly. Stream temperature data were not subdivided by treatments since most of the major stream channels lie within the lower slope clearcut. The impact of the combined treatments was most dramatic (Table 10). Average maximum temperatures increased by 3°F in November (47° to 50°F) to 19°F (60° to 79°F) in June. Changes in minimum stream temperatures were less dramatic averaging 5°F (59° to 64°F) higher in July and 7°F (45° to 38°F) lower in November. On an average basis streamwater temperatures on the treated watershed were as high as 11.5°F (72.5°F) above those measured on the control. Temperatures above 84°F were measured on several occasions. The highest temperature recorded was 89°F.

A comparison of LR-2 temperature data from a 21-day period in July 1974 with those of LR-1 further illustrates the severity of these temperature changes. After all vegetation on both the lower and middle slope clearcuts was deadened by herbicides in June 1974, maximum daily water temperature on the treated watershed during July 8-28 averaged 78°F and ranged from 67° to 82°F (Table 11). This represents a 14°F increase when compared with the 64°F average maximum daily stream temperature on the control watershed. Control

Table 8. Effects on summer peakflows after clearcutting and herbiciding 48 acres on the lower and middle slope portion of Leading Ridge Two.

Date	Measured Peakflows: Control Watershed	Measured Peakflows: Clearcut Watershed	Predicted Peakflow Clearcut Watershed	Increase in Peakflow: Volume	Increase in Peakflow: Percent
	csm	csm	csm	csm	%
6/1/74	6.43	7.13	6.75	0.38	6
6/10	0.75	3.96	0.98	2.98	304
6/15	47.00	72.84	51.38	21.46	42
6/16	3.76	10.72	4.77	5.95	125
6/19	2.12	5.74	2.85	2.89	101
6/23	3.97	7.35	5.01	2.34	47
6/30	4.78	8.79	4.94	3.85	78
7/4	1.03	6.17	1.58	4.59	292
7/5	2.15	8.08	2.89	5.19	180
7/15	0.13	1.15	0.17	0.98	565
7/24	0.12	0.90	0.16	0.74	462
7/29	0.54	7.02	0.71	6.31	894
8/12	0.07	0.93	0.10	0.83	879
8/27	0.09	0.51	0.12	0.39	321
8/28	0.25	1.25	0.33	0.92	280
8/29	0.18	1.19	0.24	0.95	400
8/30	0.48	6.26	0.63	5.63	897
8/31	0.06	0.90	0.08	0.82	997
9/1	5.47	61.07	5.70	55.37	972
9/3	3.25	29.53	4.17	25.36	608
9/7	0.07	1.28	0.10	1.18	1247
9/12	0.08	0.92	0.11	0.81	752
9/14	0.08	1.04	0.11	0.93	863
9/21	0.43	3.17	0.56	2.61	463
9/29	0.15	1.17	0.20	0.97	485
10/16	0.26	2.26	0.34	1.92	565
10/25	0.09	0.58	0.12	0.46	383
		No. of storms		27	27
		Average Increase		5.81	489

Table 9. Effects on summer peakflows after clearcutting and herbiciding 90 acres on Leading Ridge Two.

Date	Measured Peakflows		Predicted Peakflow Clearcut Watershed	Increase in Peakflow	
	Control Watershed	Clearcut Watershed		Volume	Percent
	csm	csm	csm	csm	%
6/6/77	0.97	4.05	1.26	2.78	219
6/9	0.16	0.44	0.21	0.23	107
6/17	1.19	6.37	1.76	4.61	261
6/25	0.87	11.95	1.14	10.81	953
6/28	0.74	7.02	0.97	6.05	627
7/4	0.19	1.64	0.25	1.39	553
7/11	0.12	2.61	0.16	2.45	1531
7/12	0.19	2.71	0.25	2.46	980
7/16	4.44	70.80	4.56	66.24	1451
7/19	0.57	11.03	0.75	10.28	1381
7/21	0.13	3.43	0.17	3.26	1883
7/25	1.77	25.42	2.44	22.98	941
8/6	0.09	1.04	0.12	0.92	760
8/7	0.59	10.33	0.77	9.56	1240
8/10	0.27	4.69	0.36	4.33	1221
8/16	0.13	2.11	0.17	1.94	1120
8/17	1.50	24.26	2.12	22.14	1044
9/2	0.07	0.85	0.10	0.75	795
9/16	0.51	10.21	0.67	9.54	1431
9/19	0.55	8.05	0.72	7.33	1020
9/25	4.91	58.33	5.08	53.25	1048
9/26	50.97	163.07	55.75	107.32	193
10/1	0.94	12.85	1.23	11.62	945
10/6	0.20	3.10	0.26	2.84	1091
10/9	22.14	33.10	24.03	9.07	38
10/15	3.21	8.60	4.13	4.47	108
		No. of storms		26	26
		Average Increase		14.56	882

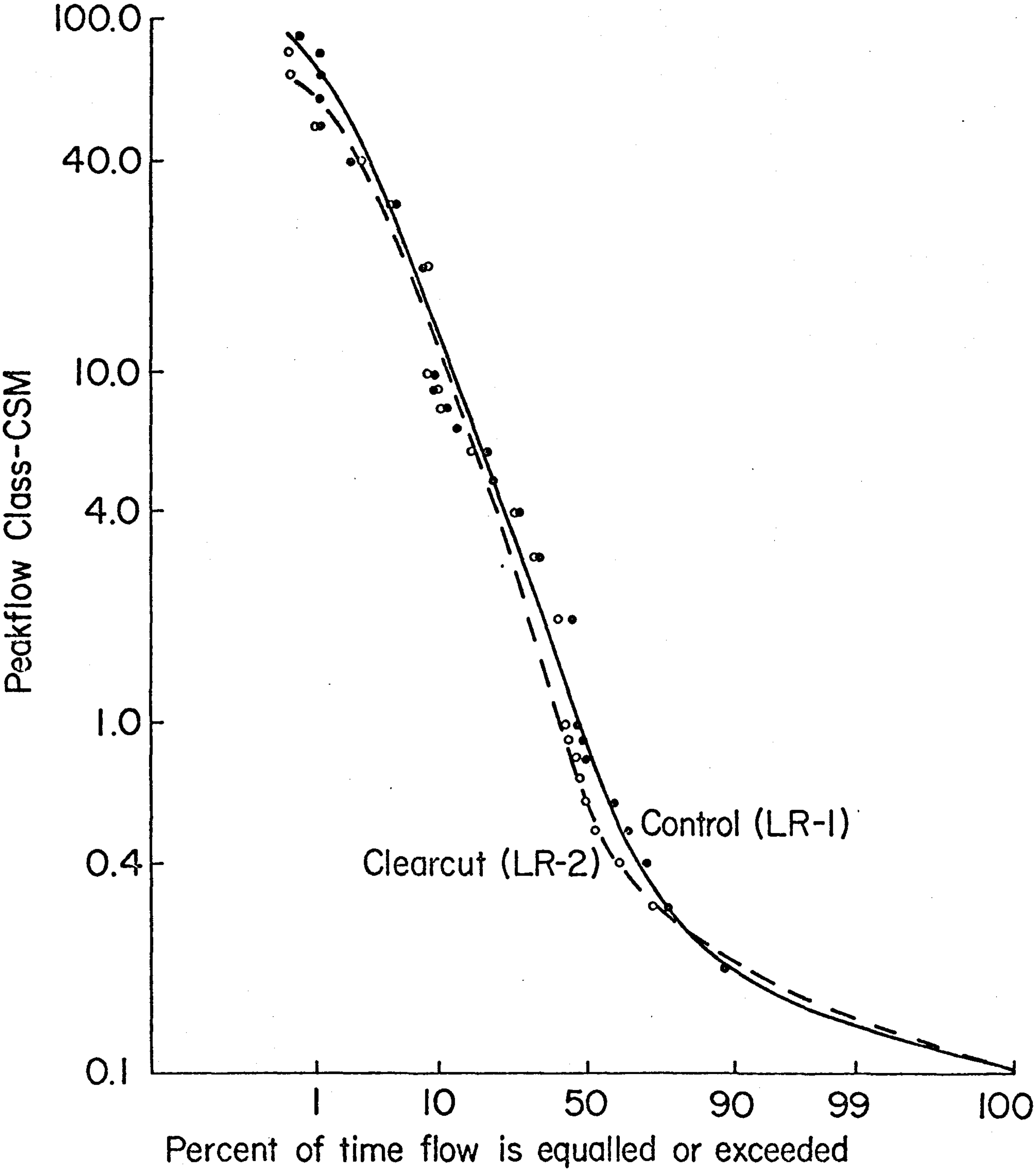


Figure 17. Summer maximum peakflow duration curves for the control and clearcut watersheds during the calibration period.

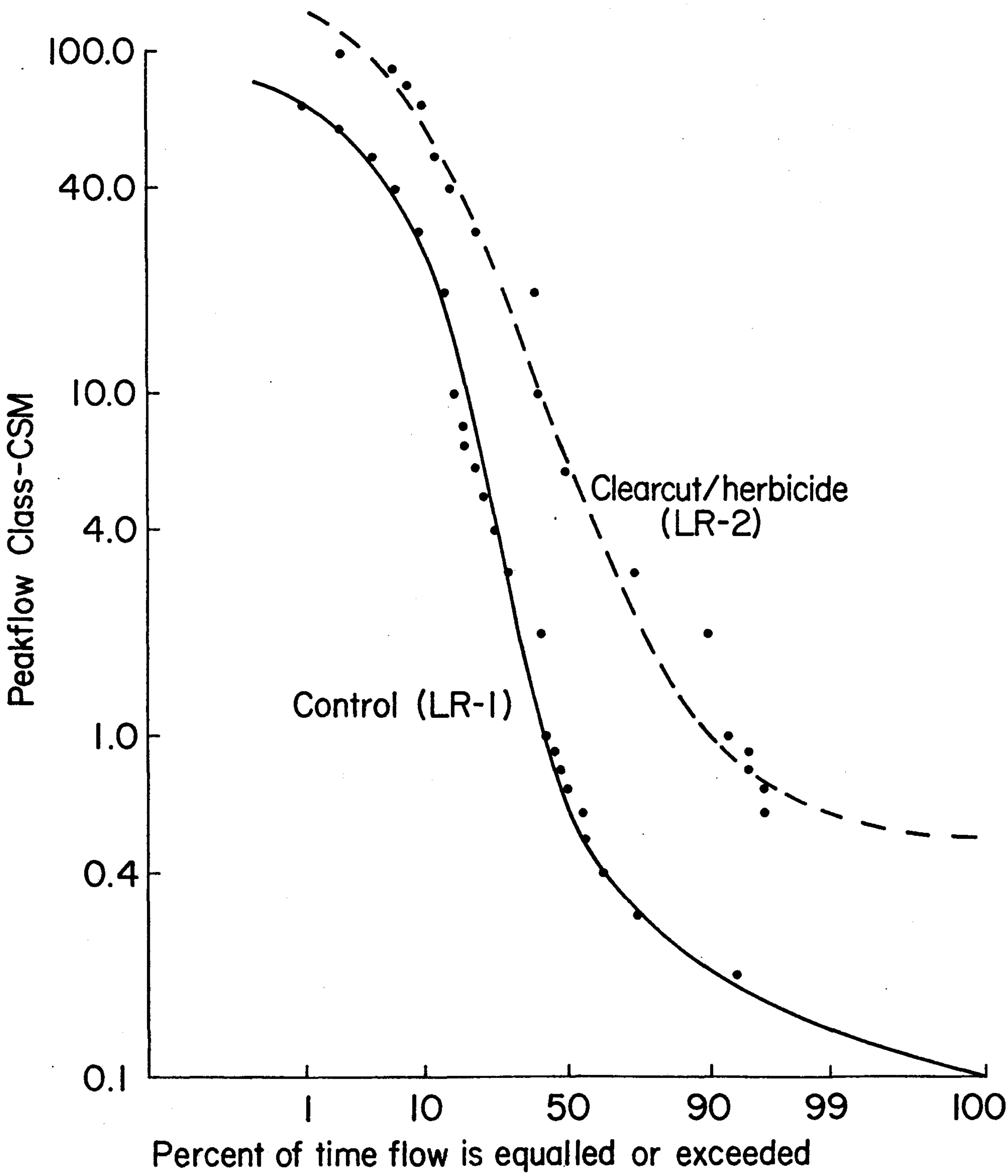


Figure 18. Summer maximum peakflow duration curves for the control and treated watersheds the first summer following the herbiciding of the 90-acre clearcut.

Table 10. Average maximum, minimum, and average daily stream temperatures on Leading Ridge One (control) and Leading Ridge Two (treated) for March through November.

		Streamwater Temperatures (°F)			
Month	Location	Maximum	Minimum	Range	Average
March	LR1	40	36	49-32	38.0
	LR2	44	36	57-33	40.0
	Difference	+ 4	0	---	+ 2.0
April	LR1	48	43	53-35	45.5
	LR2	57	43	67-37	50.0
	Difference	+ 9	0	---	+ 4.5
May	LR1	54	50	62-42	52.0
	LR2	64	51	83-39	57.5
	Difference	+10	+ 1	---	+ 5.5
June	LR1	60	56	64-50	58.0
	LR2	79	59	89-51	69.0
	Difference	+19	+ 3	---	+11.0
July	LR1	63	59	67-55	61.0
	LR2	81	64	87-57	72.5
	Difference	+18	+ 5	---	+11.5
August	LR1	64	61	67-57	62.5
	LR2	77	63	82-60	70.0
	Difference	+13	+ 2	---	+ 7.5
September	LR1	56	54	59-48	55.0
	LR2	67	55	78-46	61.0
	Difference	+11	+ 1	---	+ 6.0
October	LR1	49	46	56-38	47.5
	LR2	54	49	61-41	51.5
	Difference	+ 5	+ 3	---	+ 4.0
November	LR1	47	45	49-42	46.0
	LR2	50	38	57-34	44.0
	Difference	+ 3	- 7	---	- 2.0

Table 11. Maximum daily streamwater temperatures on control and treated watersheds during July 8-28, 1974.

Watershed	Maximum Daily Water Temperature	
	Average	Range
	---------- °F ----------	
Clearcut (LR-2)	78	(67-82)[1/]
Control (LR-1)	64	(62-68)
Difference	+14	---

[1/] On 18 of the 21 days measured, water temperature on the treated watershed exceeded 75°F for at least 15 minutes.

watershed maximums ranged from 62° to 68°F. Although daily maximum water temperature on the control watershed never exceeded 68°F, stream temperatures on the herbicided area exceeded 75°F on 18 days of this 21-day period.

The range in average daily stream temperature fluctuations increased substantially from the headwaters to the mouth of the watershed (Table 12). The perennial stream channel emerges in the upper portion of the clearcut area, where the average daily water temperature fluctuation during this 21-day period was only 1°F (56° to 57°F). At a point one-third of the distance from the headwater site to the stream-gaging station, the average daily water temperature fluctuation increased to 3°F (62° to 65°F) and at the two-thirds point to 7°F (63° to 70°F). This was still less than half the average daily range of 16°F (62° to 78°F) measured just above the stream-gaging station.

The average daily maximum water temperature changed from 57°F at the headwater to 78°F near the stream-gaging station, an increase of 21°F along the 2,600-foot section of stream. The average daily minimum temperature changed from 56°F to 62°F over the same distance, an increase of 6°F. However, the average daily minimum temperature did not change in the lower two-thirds of the stream, while the average daily maximum stream temperature increased continuously from the headwater to the mouth of the watershed (Table 12).

Although the clearcut-herbicide treatments significantly increased stream temperatures, the temperature increases were substantially moderated 500 yards below the stream-gaging station (Table 13). Average daily maximum and minimum temperatures during September 1-15, 1979 were 73°F and 63°F, respectively, after passing through the clearcut. After passing through 500 yards of undistrubed, but non-continuous forest canopy, the average daily maximum and minimum temperatures were 66°F and 58°F, respectively. Temperatures on the control watershed averaged 63°F and 60°F, respectively. This reduction in stream temperatures was attributed primarily to cooler ground water inflow and possibly to radiational cooling.

The impact of the treatments on diel temperature fluctuations was substantial (Table 14). Average diel temperature fluctuations ranged from 4.5°F in October to 19.5°F in June on the clearcut-herbicided watershed. Diel fluctuations on the control averaged 3.7°F during the 9 months studied and never exceeded 4.8°F. Diel fluctuations as high as 31°F were measured on LR-2, with fluctuations above 20°F common (Table 15). Diel fluctuations on the control basin never exceeded 10°F.

The duration of water temperature above tolerance limits for the eastern brook trout is useful in demonstrating the potential magnitude of the impact of increased temperatures on the aquatic community. Tolerance levels selected were 70°F and 84°F. These temperatures

Table 12. Fluctuation in average daily water temperature at various points along stream draining clearcut portion of Leading Ridge Watershed Two during July 8-28, 1974[1/]

Temperature	Location			
	Headwater	1/3[2/]	2/3[2/]	Weir
Avg. daily maximum	57	65	70	78
Avg. daily minimum	56	62	63	62
Avg. daily fluctuation	1	3	7	16

[1/] One month after application of herbicides to lower and middle slope clearcut.

[2/] Fractions indicate distance sampling site is between headwater of stream (near top of phase 2 clearcut) and stream gaging station.

Table 13. Average daily water temperature at and below the stream gaging station on the clearcut-herbicide watershed (LR-2) during September 1-15, 1979.

Temperature	LR-2 Weir	500 Yards Below LR-2 Weir	LR-1 Weir
		^{o}F	
Avg. daily maximum	73	66	63
Avg. daily minimum	63	58	60
Avg. daily temperature	68	62	62
Range	53-83	51-71	53-67

Table 14. Average diel temperature fluctuations on the control (LR-1) and treated (LR-2) Watersheds

Month	Watershed	Average Daily Diel Fluctuation	Range
		^{o}F	
March	LR-1	4.0	2- 8
	LR-2	8.3	1-17
	Difference	4.3	
April	LR-1	4.8	0-10
	LR-2	13.8	1-24
	Difference	9.0	
May	LR-1	4.1	0-10
	LR-2	12.7	1-25
	Difference	8.6	
June	LR-1	4.3	1- 8
	LR-2	19.5	4-31
	Difference	15.2	
July	LR-1	3.7	1- 8
	LR-2	17.0	7-26
	Difference	13.3	
August	LR-1	3.7	1- 7
	LR-2	13.5	4-22
	Difference	9.8	
September	LR-1	3.1	1- 7
	LR-2	12.1	1-25
	Difference	9.0	
October	LR-1	3.1	1- 8
	LR-2	4.5	0-11
	Difference	1.4	
November	LR-1	2.6	0- 4
	LR-2	11.4	1-18
	Difference	6.8	

Table 15. Number of days per month with diel fluctuations of over 10^{o}F and 20^{o}F on the treated watershed.

Month	No. of Days Over 10^{o}F	No. of Days Over 20^{o}F
March	6	0
April	22	7
May	20	5
June	29	18
July	28	11
August	25	2
September	21	5
October	2	0
November	11	0

were selected because the brook trout, which is generally native in many headwater streams in the east, is under stress at 70°F, with mortality occurring within 30 minutes at 84°F. Following treatment, temperatures of 70°F or higher occurred frequently during May through September (Table 16). The duration of these temperatures ranged from 1.3 hours to over 19 hours. Temperatures above 84°F occurred on 6 days during both June and July. The duration of these 84°F temperatures ranged from 45 minutes to nearly 4 hours. Water temperature on the control basin during the entire post-treatment period (1973-1979) exceeded 70°F only once.

Turbidity-Sediment Loading

The effects of forest treatments on the sediment load carried by streams vary considerably. Some forest areas can undergo severe treatment and remain relatively stable. Others erode severely after only slight disturbance. Such differences in the hydrologic behavior and stability characteristics of forestland can usually be traced to variations in climate, topography, geology, and soils. These variations tend to be balanced by vegetation in ways that promote soil stability in most forest regions.

The highest turbidity recorded during logging the 21-acre lower slope clearcut was 550 JTU (Table 17). The next highest turbidity recorded was 129 JTU. Increased stream turbidity, which could be traced to sacrified log-loading areas, decreased immediately after completion of logging. Average storm turbidity from the clearcut decreased from 196 JTU during logging to 11 JTU the first year after logging, and ranged from 3 to 13 JTU during the next four post-treatment years. On the control watershed, storm turbidity never exceeded 29 JTU and consistently averaged less than 5 JTU during the study.

An insufficient number of storms occurred during the actual logging of the middle slope timber harvest on Leading Ridge Watershed Two to determine its effects on storm turbidity. However, nonstorm turbidity measurements indicated that the effects of the middle slope cutting on stream turbidity were considerably less than those from the lower slope cubting (Table 17). Nonstorm turbidity measurements made during this period averaged only 2 JTU on both the treated and control watersheds. Maximum nonstorm turbidity measured were 11 JTU on the treated watershed and 7 JTU on the control watershed.

Storm turbidity samples taken the first year after completion of the middle slope logging operation averaged 4 JTU on the treated watershed and 2 JTU on the control watershed. Maximum storm turbidity during this period was 13 JTU on the treated area and 7 JTU on the control. Nonstorm turbidity the first year after completion of logging never exceeded 6 JTU and averaged only 1 JTU on both the treated and control watersheds.

Table 16. Number of days and duration that streamwater on the treated watershed exceeded 70°F and 84°F.

	Temperature °F			
	70°		84°	
Month	Days	Range of Time	Days	Range of Time
		Hr:Min		Hr:Min
March	0	---	0	---
April	0	---	0	---
May	8	2:16-9:12	0	---
June	26	1:20-13:41	6	1:28-3:55
July	31	5:19-19:06	6	0:45-3:44
August	31	2:41-13:19	0	---
September	10	2:26-7:16	0	---
October	0	---	0	---
November	0	---	0	---

Table 17. Streamflow turbidity values for Leading Ridge watersheds during and following the lower and middle slope clear-cut treatments.[1/]

Treatment and Period	Storm Turbidity		Non-storm Turbidity	
	Avg.	Max.	Avg.	Max.
Lower slope clearcut				
During logging	196	550	-	-
After logging (4 years)	9	119	2	24
Undisturbed control	3	29	1	17
Middle slope clearcut				
During logging	-	-	2	11
After logging (2 years)	4	13	1	6
Undisturbed control	2	7	2	7

[1/]Turbidity values during the upper slope and ridge top cutting are not included since no additional stream channels were included in the cutover area.

No storm turbidity data were collected during the actual cutting of the upper slope and ridge top since no streams were involved in the cutover area. However, routine and storm turbidity data were collected during 1977 and 1978 following the herbicide spraying of the entire 90-acre clearcut (Table 18). The increase in streamflow and particularly storm runoff and peakflow rates (Table 9, Figure 18) resulted in an acceleration of channel erosion and bank slumping in the lower portion of the watershed, which in turn significantly increased streamwater turbidity and sedimentation. Streamwater turbidity measurements on LR-2 were as high as 69 NTU and averaged over 15 NTU throughout the entire 1978 water year. In comparison, turbidity on the control watershed never exceeded 13 NTU and averaged only 2.2 throughout 1978. The LR-2 turbidity levels greatly exceeded the recommended levels set forth in the Federal Safe Drinking Water Act of 1974. It should be noted that the average in-stream turbidity levels on the control watershed also exceeded the recommended Safe Drinking Water standards. It should also be pointed out that these high turbidity levels are not a direct result of improper harvesting methods but instead an indirect result due to the increase in storm runoff due to the complete deadening of all vegetation on the cutover area.

The average concentration of suspended sediment in streamwater on Leading Ridge Two following the herbicide application to the 90-acre clearcut are given in Table 19. It is readily apparent that the amount of suspended sediment has increased greatly. The average annual suspended sediment concentration on LR-2 during 1978 was more than 78 mg/l as compared to 10.4 mg/l on the control watershed. This increased loading was directly attributable to channel cutting and bank erosion and slumping on the lower portion of the stream channel which was caused by the increase in the frequency and magnitude of storm flows.

The 1977 average annual suspended sediment concentrations in Table 19 are equivalent to 0.005 and 0.04 tons/acre/year for LR-1 and LR-2, respectively. The 1978 equivalent values are 0.01 and 0.27 tons/acre/year. By comparison, other studies have shown that the average annual erosion loss from undisturbed as well as carefully managed forest land in the East is 0.05 to 0.10 tons/acre/year; that is less than the geologic norm (0.18 to 0.3) and far less than maximum tolerable rates for agricultural land (1 to 5 tons/acre/year).

Nutrient Concentrations

Weekly sampling for nutrient concentrations began in 1973. No calibration data are available. Consequently, a direct comparision between the clearcut and control watersheds was necessary to evaluate treatment effects. Under such a comparison, it was necessary to assume that the nutrient concentrations on the control watershed represented the uncut condition on the treated watershed and that any major difference would represent a possible treatment effect. This assumption was justified on the basis of the similarities of the vegetation, soils, and geology on the watersheds.

Table 18. Streamwater turbidity on Leading Ridge Two following the herbicide application to the 90-acre clearcut.

Year and Location	Streamwater Turbidity (NTU)					
	Growing Season		Dormant Season		Annual	
	Avg.	Range	Avg.	Range	Avg.	Range
1977						
LR-1	1.4	(0.3-8.4)	2.0	(0.7-4.0)	1.5	(0.3-8.4)
LR-2	5.6	(1.4-13.0)	3.8	(1.1-8.0)	5.2	(1.1-13.0)
1978						
LR-1	3.2	(0.8-13.0)	1.6	(0.3-3.0)	2.2	(0.3-13.0)
LR-2	14.0	(3.5-69.0)	16.6	(0.8-67.0)	15.6	(0.8-69.0)

Table 19. Streamwater sediment concentrations on Leading Ridge One (control) and Two (treated) following the herbicide application to the 90-acre clearcut.

Year and Location	Growing Season Avg.	Growing Season Range	Dormant Season Avg.	Dormant Season Range	Annual Avg.	Annual Range
	mg/l					
1977						
LR-1	2.1	(0.2-8.0)	0.4	(0.2-0.7)	1.7	(0.2-8.6)
LR-2	11.8	(2.3-30.5)	5.3	(3.0-9.7)	10.4	(2.3-30.5)
1978						
LR-1	8.8	(0.3-33.5)	2.7	(0.3-6.8)	5.2	(0.2-33.5)
LR-2	51.3	(9.7-268.0)	97.0	(1.8-380.3)	78.7	(1.8-380.0)

The average nutrient concentrations of streamwater for the treated and control watersheds following completion of the middle slope clearcutting for the period 10/15/73 to 5/31/74 are given in Table 20. Since these data represent only an 8½ month period following cutting, they are not intended to represent exact average monthly concentrations of the listed parameters. Instead they are presented merely to show that clearcutting had little if any apparent effect on these parameters. Only sulfate was significantly different on the treated watershed than on the control.

After all vegetation on the 48-acre clearcut was deadened in June 1974, there were substantial changes in nutrient concentrations on the treated watershed (Table 20). Potassium and nitrate-nitrogen increased while sulfate and calcium carbonate (alkalinity) decreased. Nitrate-nitrogen showed the biggest increase (0.04 to 2.04 mg/l), while calcium carbonate was more than 11 mg/l below the control watershed. Since sulfate was significantly lower on the treated area before herbiciding, it is uncertain whether the deadening of the vegetation resulted in a further reduction. Potassium responded rather rapidly to treatment and was approximately 0.5 mg/l above the control. Nitrate-nitrogen concentration remained below 0.4 mg/l for the first three months after herbiciding and then increased sharply from September through December. The maximum average monthly concentration of nitrate-nitrogen was 5.0 mg/l; the maximum concentration measured following the herbiciding of the lower and middle slope clearcuts was 8.4 mg/l.

During the second year following herbiciding, nitrate-nitrogen concentrations remained significently higher on the treated watershed (Table 20); however, the magnitude of the increase was approximately one-fourth of the preceding year. Sulfate remained at about the same level; however, calcium carbonate concentrations were no longer significantly different statistically than the control. The potassium concentrations also dropped to near pre-herbiciding levels. The only other element that responded to treatment during the second year was magnesium, which declined when compared to the control (2.07 vs. 1.40 mg/l). In general, the lower concentrations were a result of a decline in availability of the ions due to regrowth on the sprayed area.

During the lower and middle slope post-treatment period, concentrations of nutrients in streamflow on the clearcut watershed generally increased from the headwater to the mouth of the watershed (Table 21). This reflected, in part, the geologic formations over which the stream flowed and opportunities for soil-water leaching. Except for nitrate-nitrogen, there was no evidence of significant changes in nutrient concentrations in the upper half of the stream draining the clearcut watershed during October 1973 through May 1974. Nitrate-nitrogen increased from 0.04 mg/l at the headwater of the clearcut watershed to 0.19 mg/l at a point on the stream one-half the distance between the headwater and the mouth of the watershed.

Table 20. Average nutrient concentrations of streamwater for treated and control watersheds following the middle slope clearcut and herbicide treatment.

Parameter	Watershed Control	Watershed Treated
Treatment/period: 48-acre clearcut/10-15-73 to 5-31-74		
Calcium, mg/l	4.36	2.29
Magnesium, mg/l	1.96	1.24
Potassium, mg/l	1.16	1.15
Sodium, mg/l	0.97	0.87
pH	6.69	6.57
Calcium carbonate, mg/l	11.05	5.07
Nitrate-nitrogen, mg/l	0.02	0.10
Sulfate, mg/l	9.16	6.40*
Specific conductance, µmho/cm	49.4	32.3
Treatment/period: 48-acre clearcut-herbicided/6-1-74 to 5-31-75 (first year)		
Calcium, mg/l	3.86	2.48
Magnesium, mg/l	2.26	1.92
Potassium, mg/l	0.87	1.41*
Sodium, mg/l	0.91	0.90
pH	7.06	6.77
Calcium carbonate, mg/l	16.58	5.25*
Nitrate-nitrogen, mg/l	0.04	2.04*
Sulfate, mg/l	8.38	5.00*
Specific conductance, µmho/cm	53.6	45.2
Treatment/period: 48-acre clearcut-herbicided/6-1-75 to 5-31-76 (second year)		
Calcium, mg/l	4.14	2.72
Magnesium, mg/l	2.07	1.40*
Potassium, mg/l	0.96	1.12
Sodium, mg/l	1.00	1.06
pH	6.79	6.71
Calcium carbonate, mg/l	12.48	6.78
Nitrate-nitrogen, mg/l	0.03	0.58*
Sulfate, mg/l	8.28	5.10*
Specific conductance, µmho/cm	45.3	33.3

*Significant at 10 percent.

Table 21. Average nutrient concentrations of streamwater on treated watershed from headwaters to stream-gaging station.

Parameter	Sample Site Location[1/] Headwater	1/3	1/2	Weir
Treatment/Period: 48-acre clearcut/6-15-73 to 5-31-74				
Calcium, mg/l	0.75	0.87	1.17	2.29
Magnesium, mg/l	0.66	0.69	0.86	1.24
Potassium, mg/l	1.13	1.13	1.20	1.15
Sodium, mg/l	0.55	0.63	0.81	0.87
pH	5.87	5.86	6.14	6.57
Calcium carbonate, mg/l	1.27	1.10	1.98	5.07
Nitrate-nitrogen, mg/l	0.04	0.14	0.19	0.10
Sulfate, mg/l	3.6	3.7	4.2	6.4
Specific conductance, μmho/cm	18.1	19.4	22.8	32.3
Treatment/Period: 48-acre clearcut-herbicided/6-1-74 to 5-31-75				
Calcium, mg/l	0.63	1.02	1.51	2.48
Magnesium, mg/l	0.70	1.06	1.51	1.92
Potassium, mg/l	0.90	1.14	1.34	1.41
Sodium, mg/l	0.43	0.56	0.69	0.90
pH	6.10	6.13	6.18	6.77
Calcium carbonate, mg/l	1.53	1.60	1.76	5.25
Nitrate-nitrogen, mg/l	0.20	1.42	2.08	2.04
Sulfate, mg/l	3.8	3.4	3.8	5.0
Specific conductance, μmho/cm	17.5	26.4	34.9	45.2

[1/] Fractions indicate distance sampling site is between headwater of stream (near top of middle slope clearcut) and weir.

After deadening all vegetation with herbicides, in June 1974, there was a large increase in nitrate-nitrogen at the headwater site (located in the upper portion of the phase-2 clearcut). The increase was larger farther downstream, especially in the middle portion of the clearcut at the one-third and one-half distance sampling points (Table 21). By comparison, the increase in NO_3-N was more attributable to the more recent middle slope clearcut than to the lower slope cut. Similar increases were also observed for potassium.

Average nutrient concentrations of streamwater on the treated and control watersheds the first year following completion of the upper slope and ridge top clearcutting are given in Table 22. Only magnesium concentrations remained significantly different in comparison to the control watershed. Nitrate-nitrogen concentrations declined during this period to 0.23 mg/l and were not statistically significantly different from the control. This lack of response of nutrients to increased-leaching following the additional 42-acre clearcut apparently reflects the fact that no stream channels are within the phase three clearcut. This apparently reduced or limited the potential for nutrient leaching. In addition, regrowth of vegetation on the lower and middle slopes resulted in the retention of nutrients on site. Nutrients transported into this area from above would also be available for uptake, thus lessening their potential movement into the stream.

The utilization of available nutrients by herbacious and woody vegetation and subsequent lessening of the potential for nutrient leaching is dramatically illustrated by the first year nutrient data following the aerial application of herbicides to the entire 90-acre clearcut (Table 22). Deadening the vegetation resulted in substantial increases in the average annual potassium (0.95 vs. 1.57 mg/l) and nitrate-nitrogen (0.11 vs. 2.54 mg/l) concentrations when compared with the control watershed. The average annual concentrations of calcium carbonate and sulfate decreased significantly.

The overall effect of the herbiciding appeared to be a decrease in the total concentration of dissolved substances in streamwater as indicated by a significant reduction in specific conductivity. This may be due to a dilution effect caused by the increased water yields. Average monthly specific conductivity and nutrient concentration data for the period 10/73 through 9/78 are presented graphically in Figures 19 through 26.

The effects of the 90-acre clearcut herbicide treatment on nitrate-nitrogen concentrations are of particular importance because of its potential health hazard. The average annual concentration of nitrate-nitrogen in streamwater the first year after treatment was 2.54 mg/l (Table 22). This average is well below the recommended safe drinking water level of 10 mg/l. However, it should be pointed out that nitrate-nitrogen concentrations did exceed 10 mg/l at several sampling points along the stream. The average nitrate-nitrogen concentration in the middle of the lower slope clearcut was 8.15 mg/l during the month of October 1977.

Table 22. Average nutrient concentrations of streamwater for treated and control watersheds following the upper slope clearcut and herbicide treatment.

Parameter	Watershed: Control	Watershed: Treated
Treatment/period: 90-acre clearcut/6-1-76 to 6-8-77		
Calcium, mg/l	5.04	2.57
Magnesium, mg/l	1.92	1.09*
Potassium, mg/l	0.73	0.87
Sodium, mg/l	0.88	0.78
pH	6.82	6.68
Calcium carbonate, mg/l	13.25	5.65
Nitrate-nitrogen, mg/l	0.05	0.23
Sulfate, mg/l	8.23	5.00
Specific conductance, μmho/cm	48.6	29.6
Treatment/period: 90-acre clearcut-herbicided/6-9-77 to 5-31-78		
Calcium, mg/l	5.06	3.15
Magnesium, mg/l	2.05	1.76
Potassium, mg/l	0.95	1.57*
Sodium, mg/l	0.98	0.93
pH	6.75	6.36
Calcium carbonate, mg/l	14.87	3.79*
Nitrate-nitrogen, mg/l	0.11	2.54*
Sulfate, mg/l	7.92	3.87*
Specific conductance, μmho/cm	74.6	45.2*

*Significant at 10 percent.

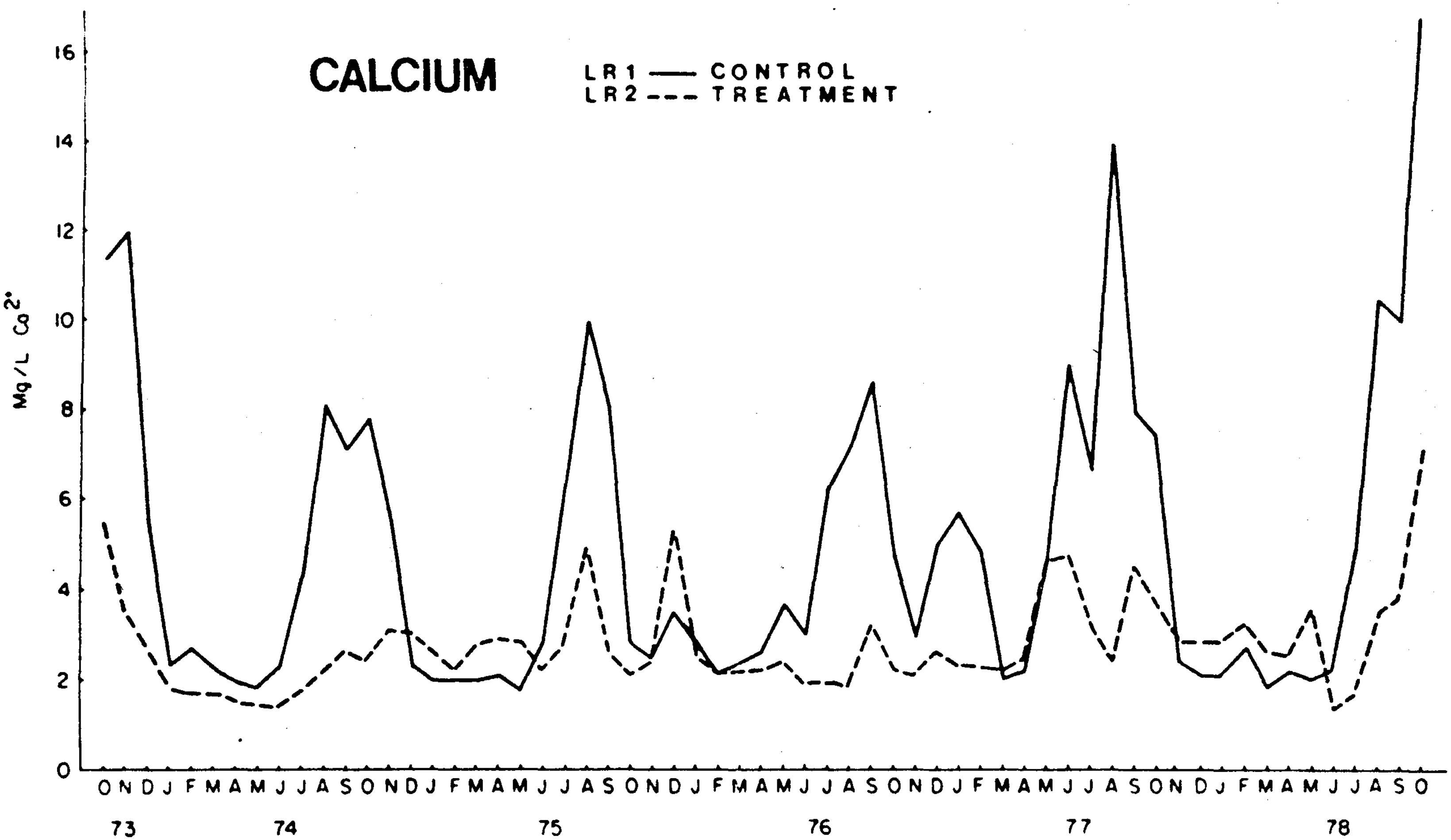


Figure 19. Average monthly concentration of calcium on the treated and control watersheds from October 1973 through October 1978.

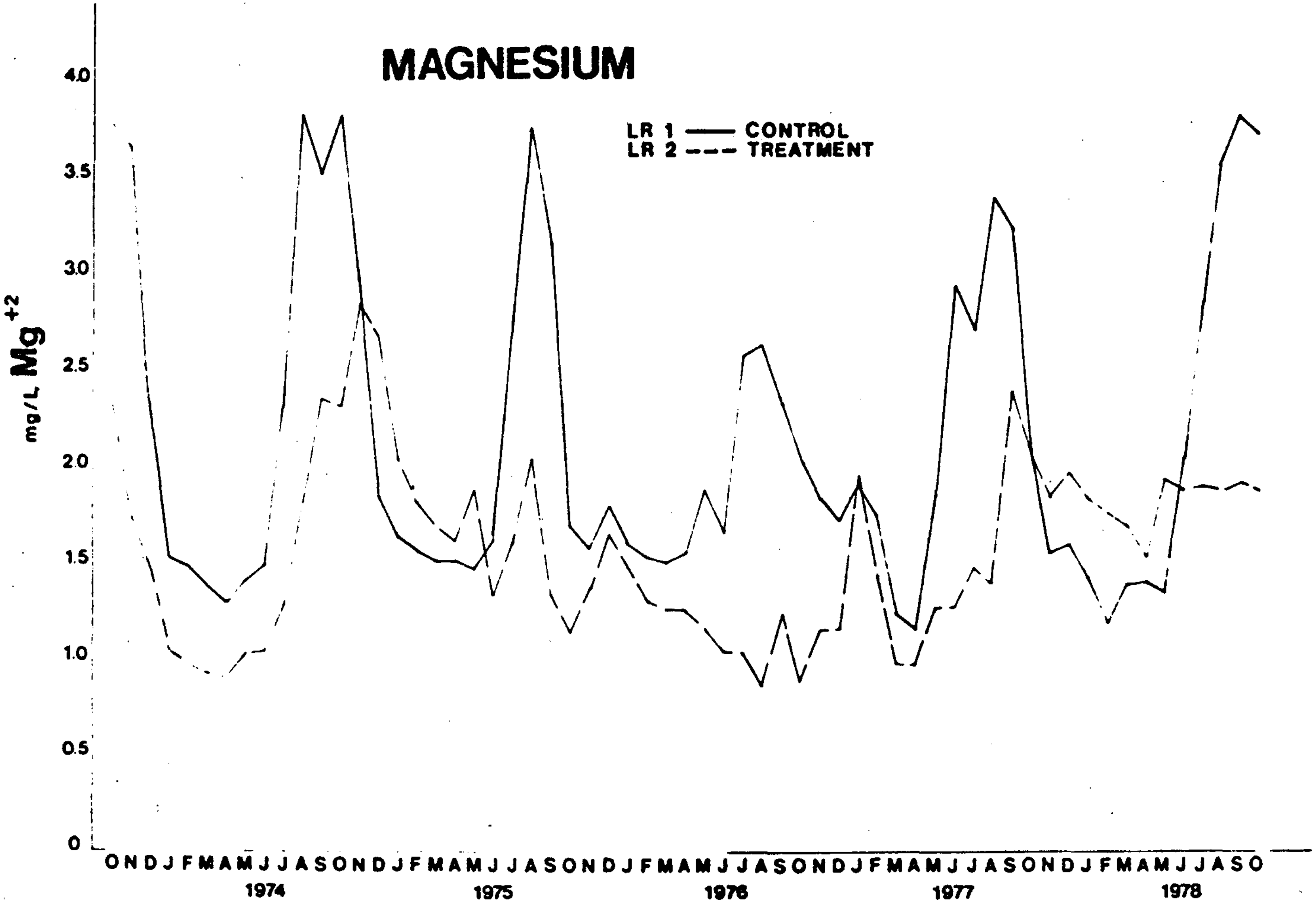


Figure 20. Average monthly concentration of magnesium on the treated and control watersheds from October 1973 through October 1978.

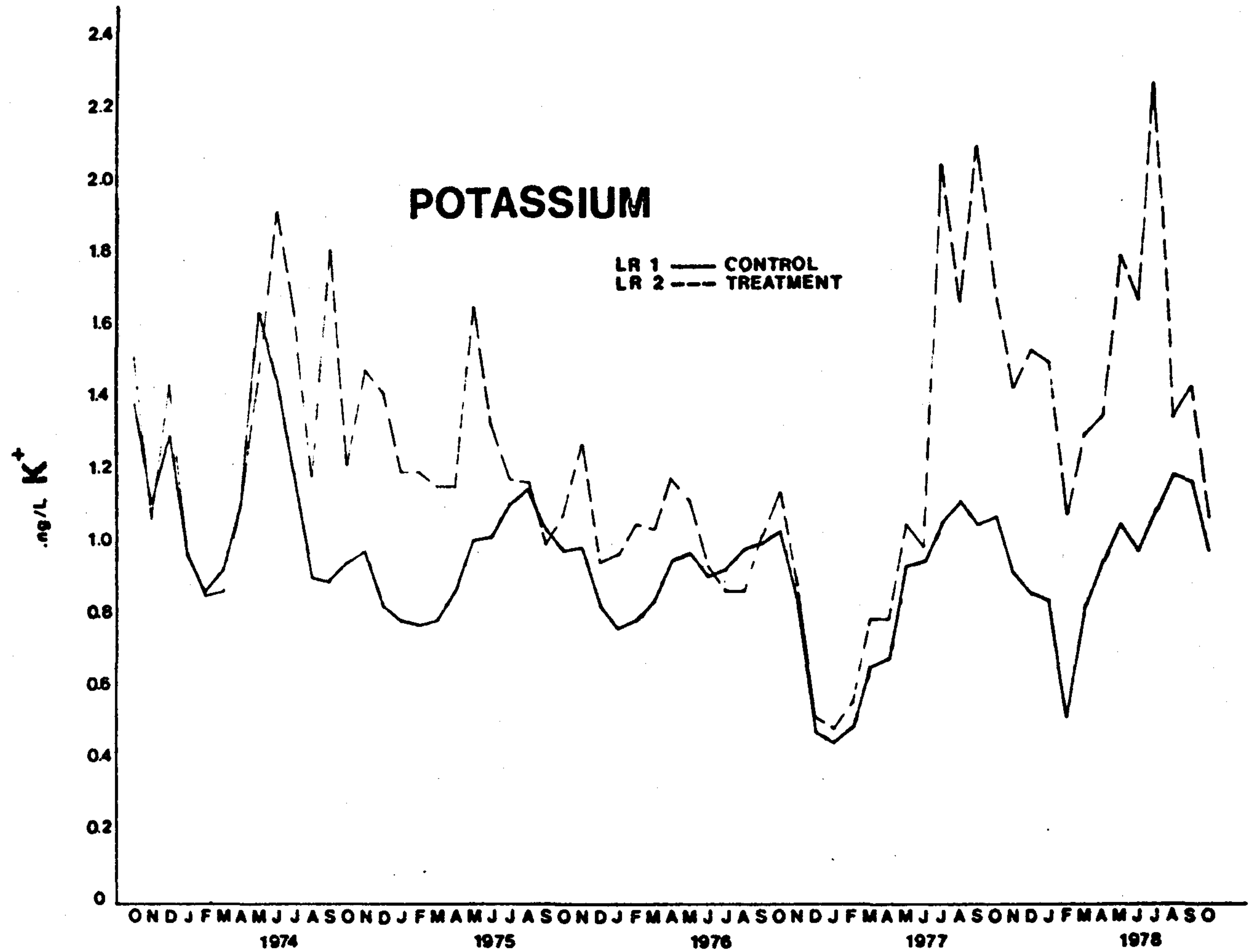


Figure 21. Average monthly concentration of potassium on the treated and control watersheds from October 1973 through October 1978.

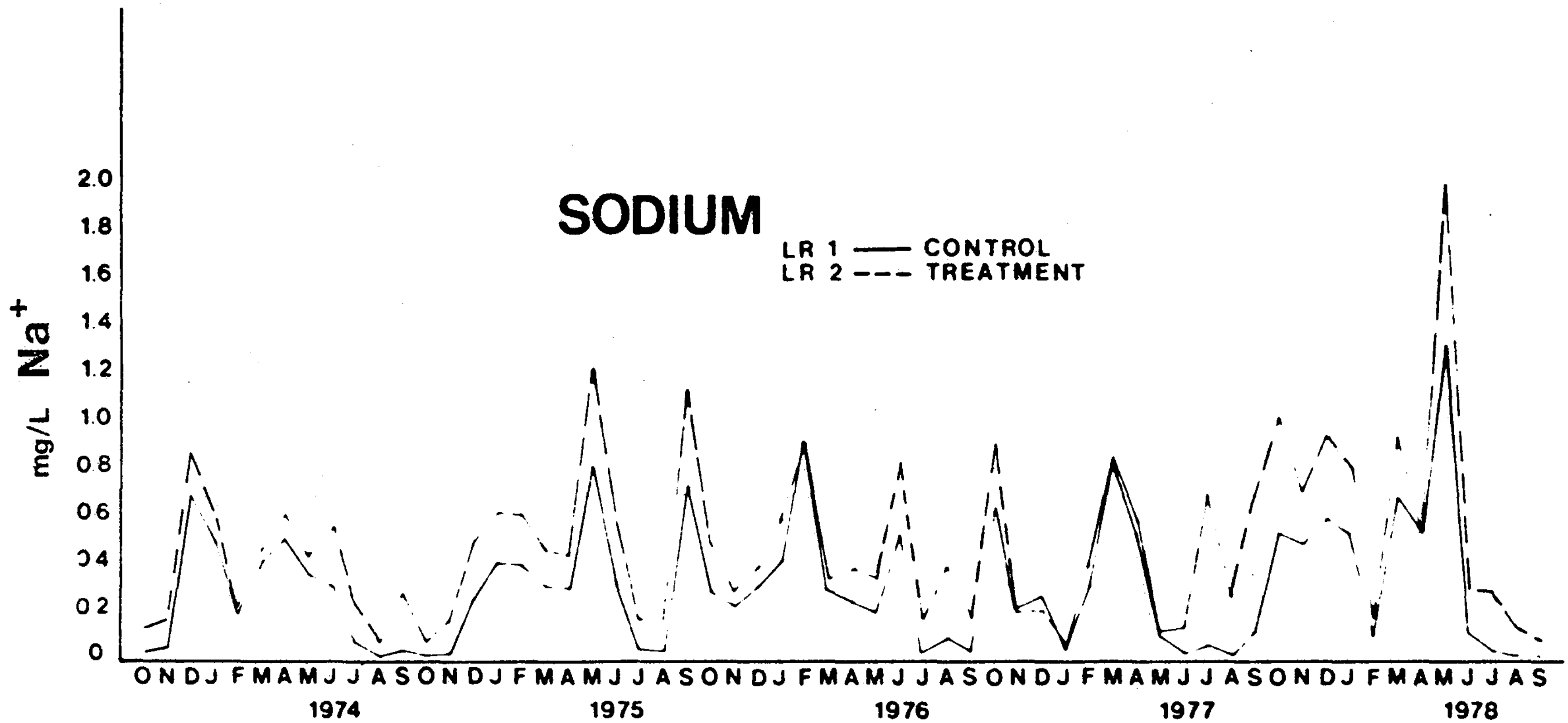


Figure 22. Average monthly concentration of sodium on the treated and control watersheds from October 1973 through October 1978.

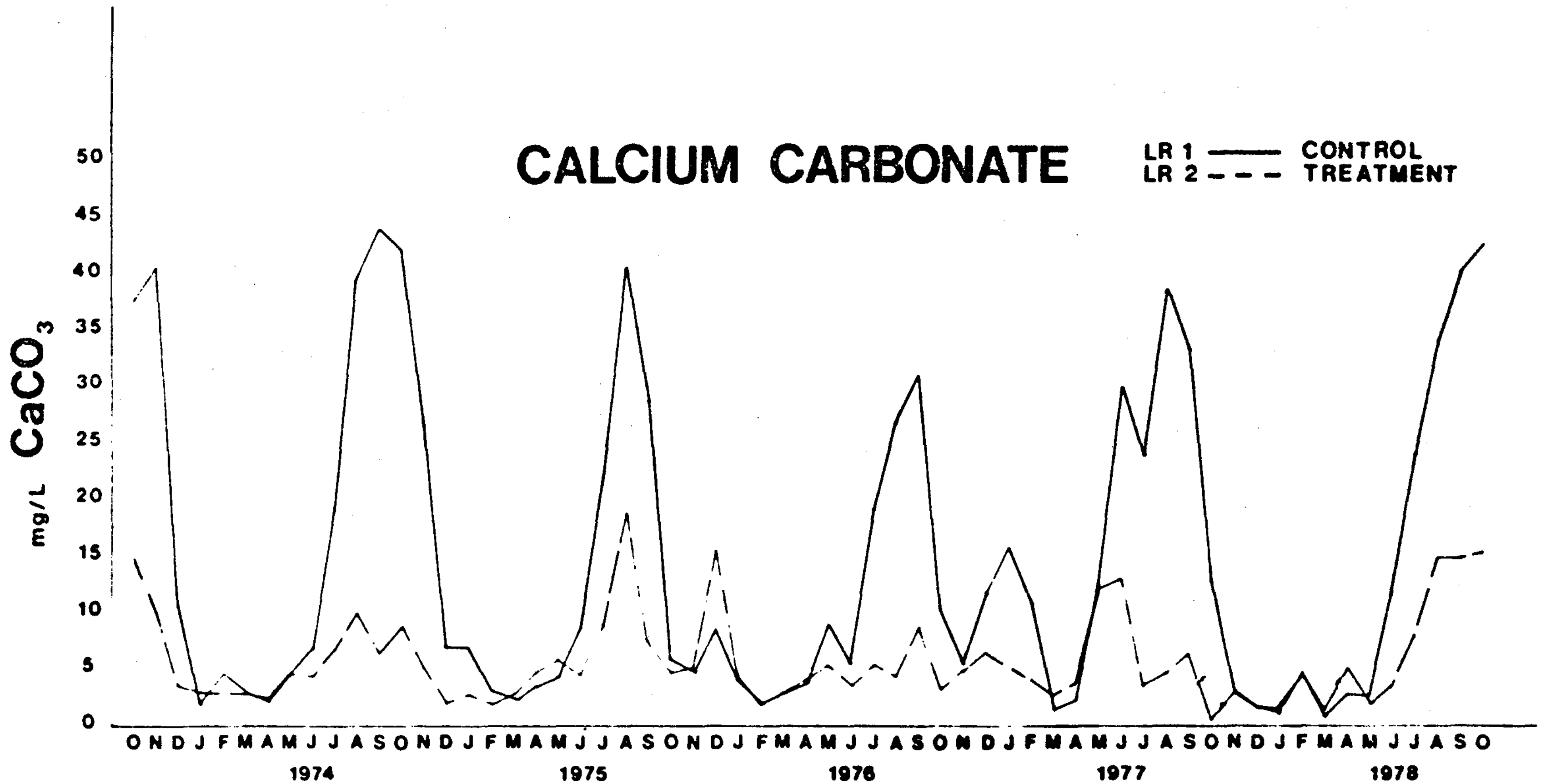


Figure 23. Average monthly concentration of calcium carbonate on the treated and control watersheds from October 1973 through October 1978.

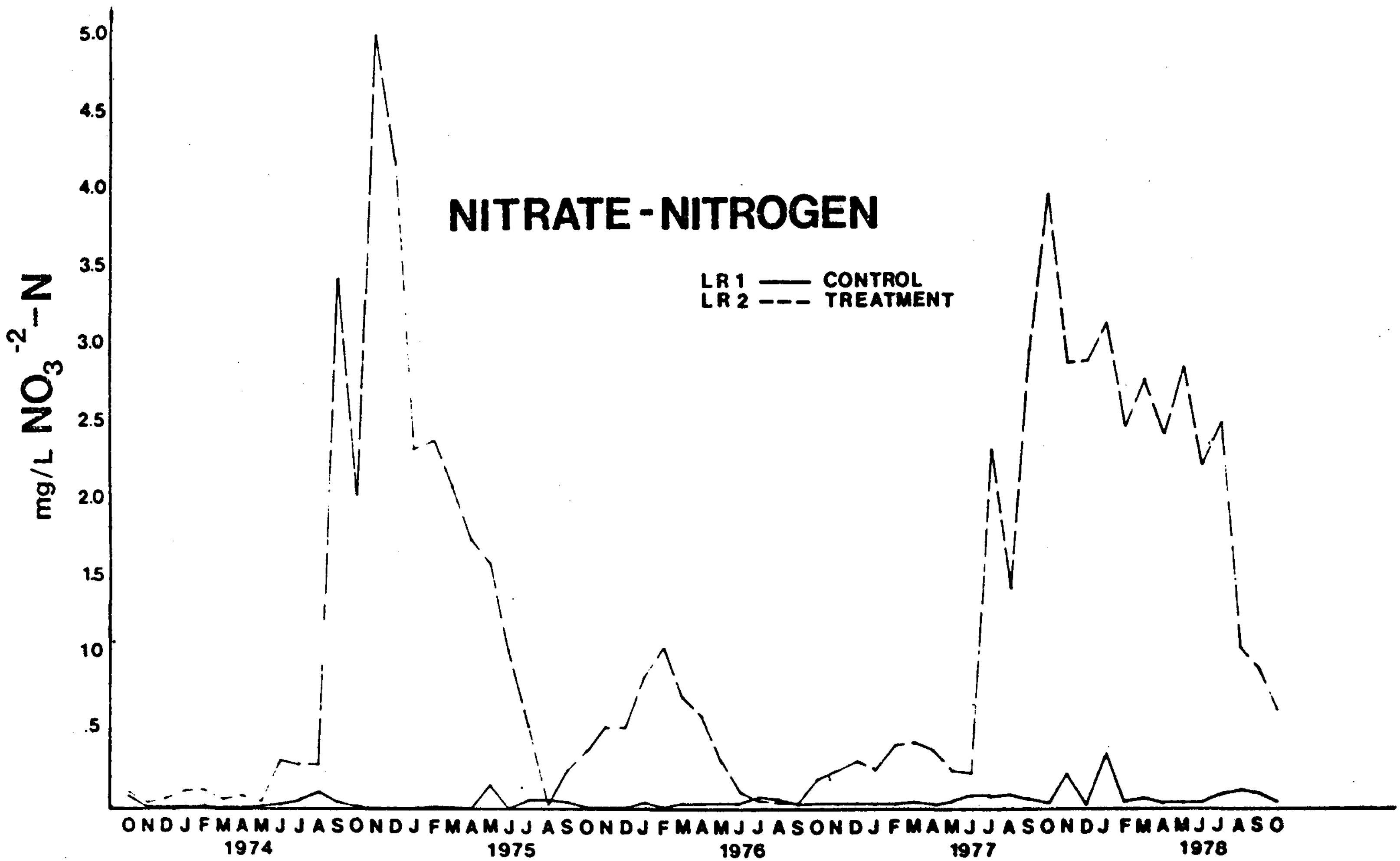


Figure 24. Average monthly concentration of nitrate-nitrogen on the treated and control watersheds from October 1973 through October 1978.

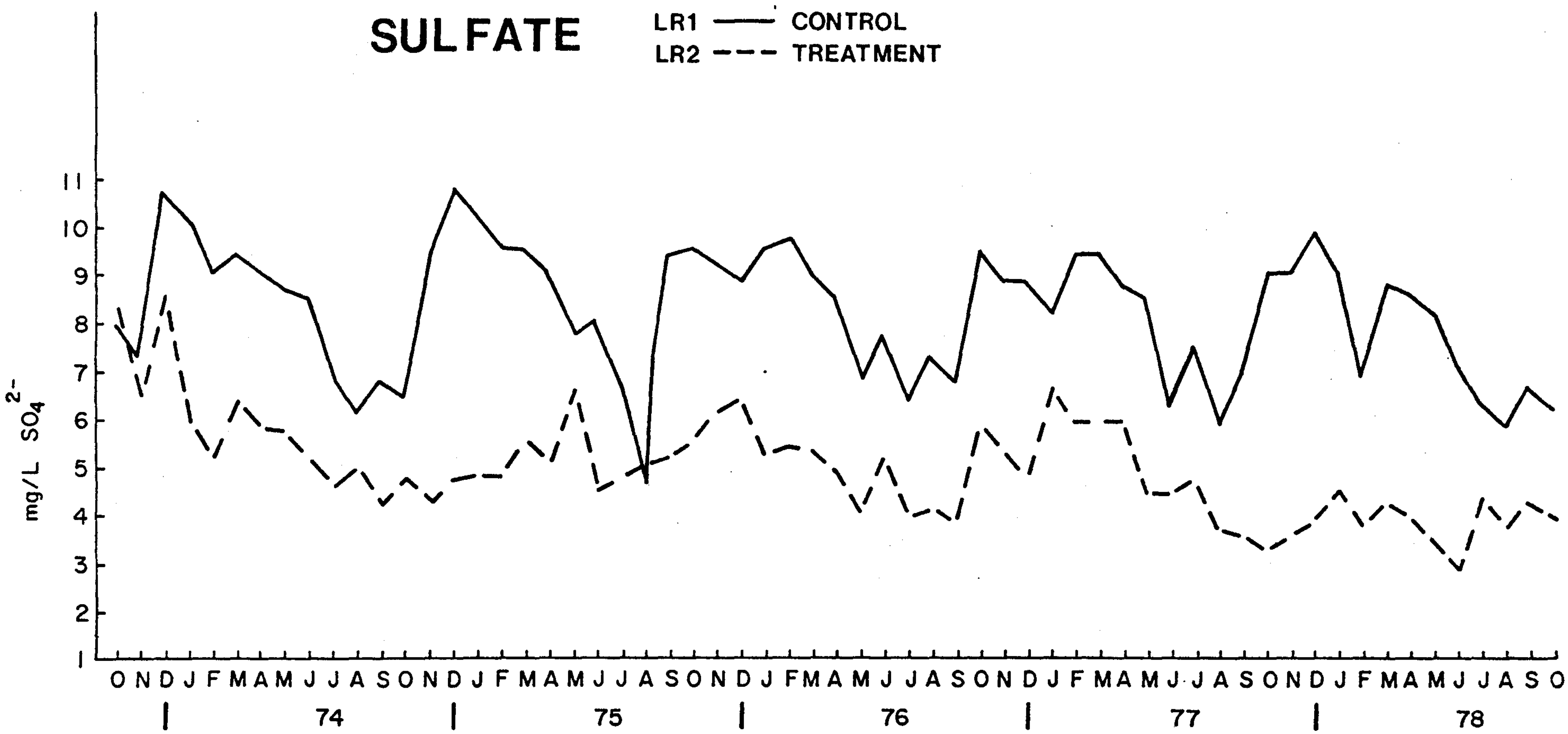


Figure 25. Average monthly concentration of sulfate on the treated and control watersheds from October 1973 through October 1978.

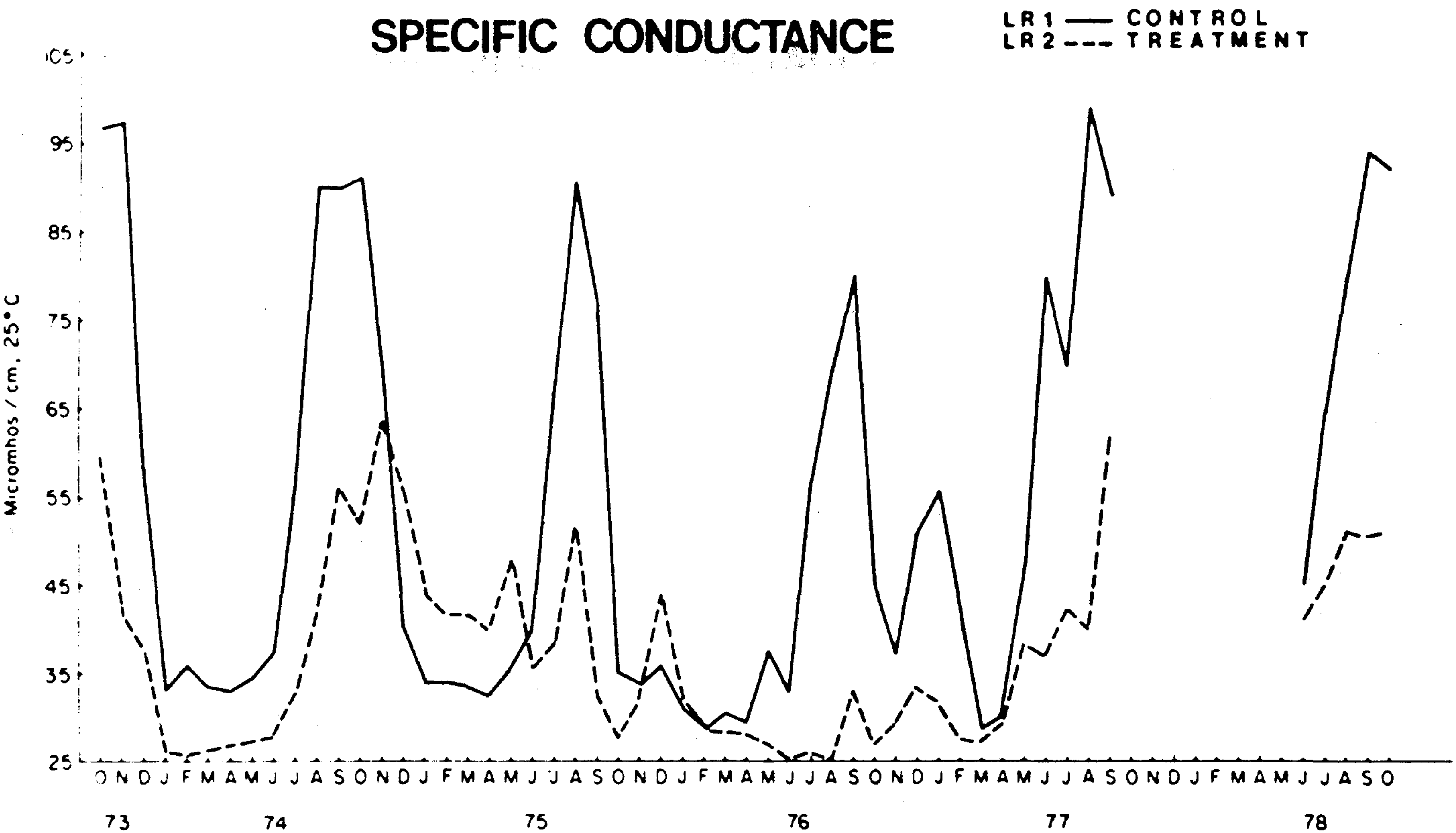


Figure 26. Average monthly specific conductance on the treated and control watersheds from October 1973 through October 1978.

It is also interesting to note that intra-watershed sampling during the first year after herbiciding the 90-acre clearcut revealed that the concentrations of the nutrients studied generally increased from the headwater to the mouth of the watershed, the same as noted after the 48-acre clearcut-herbicide treatment. The intra-watershed sampling also revealed that the source of most of the potassium and nitrate-nitrogen present in the stream came from the middle slope portion of the watershed. While higher concentrations of nitrate-nitrogen and potassium were measured at the headwater than previously, the increases were small, indicating little nutrient leaching from the upper slope and ridge top. The second year following the 90-acre herbiciding this trend was reversed for nitrate-nitrogen. Nitrate-nitrogen concentrations during the latter part of 1978 and continuing into 1979 were continually higher at the headwater than at the mouth of the watershed. Concentrations at the headwater have been one to two mg/l higher than at the weir. This delay in the release of nitrate-nitrogen from the upper slope area was apparently related to the rate of decomposition of organic matter. Several years were needed before decomposition of the logging debris was sufficient to convert organic nitrogen into more soluble forms. Dilution and uptake by vegetation in the lower half of the watershed were responsible for the decrease.

Nutrient Loading

The total change in stream chemistry is not represented completely by concentration data alone. The increase in stream discharge that accompanies timber harvesting can significantly increase the loss of nutrients while at the same time have little effect or actually decrease concentrations of various ions by dilution. Consequently, the total effect on stream chemistry and nutrient loss must be computed in discharge terms, referred to as loadings. Average monthly nutrient loading data for calcium, magnesium, potassium, sodium, calcium carbonate, nitrate-nitrogen and sulfate are presented graphically in Figures 27 through 33, respectively.

Analysis of the loading differences between the control and treated watershed showed that nutrient loading followed a pattern very similar to the concentration data. The average nutrient loadings of streamwater for the treated and control watersheds following completion of the middle slope clearcutting for the period 10/15/73 to 5/31/74 are given in Table 23. Clearcutting had little effect on the loading rates of most of the nutrients studied. Only sodium, potassium, and nitrate-nitrogen were significantly different on the treated watershed than on the control. The higher sodium export appeared to be a result of increased stream discharge. The increased nitrogen and potassium loading were a result of both increased concentrations and increased stream discharge.

After all vegetation on the 48-acre clearcut was deadened with herbicides on June 3, 1974, there were substantial changes in nutrient loading on the treated basin (Table 23). Calcium, magnesium, and sodium export increased due to increased discharge. The concentrations

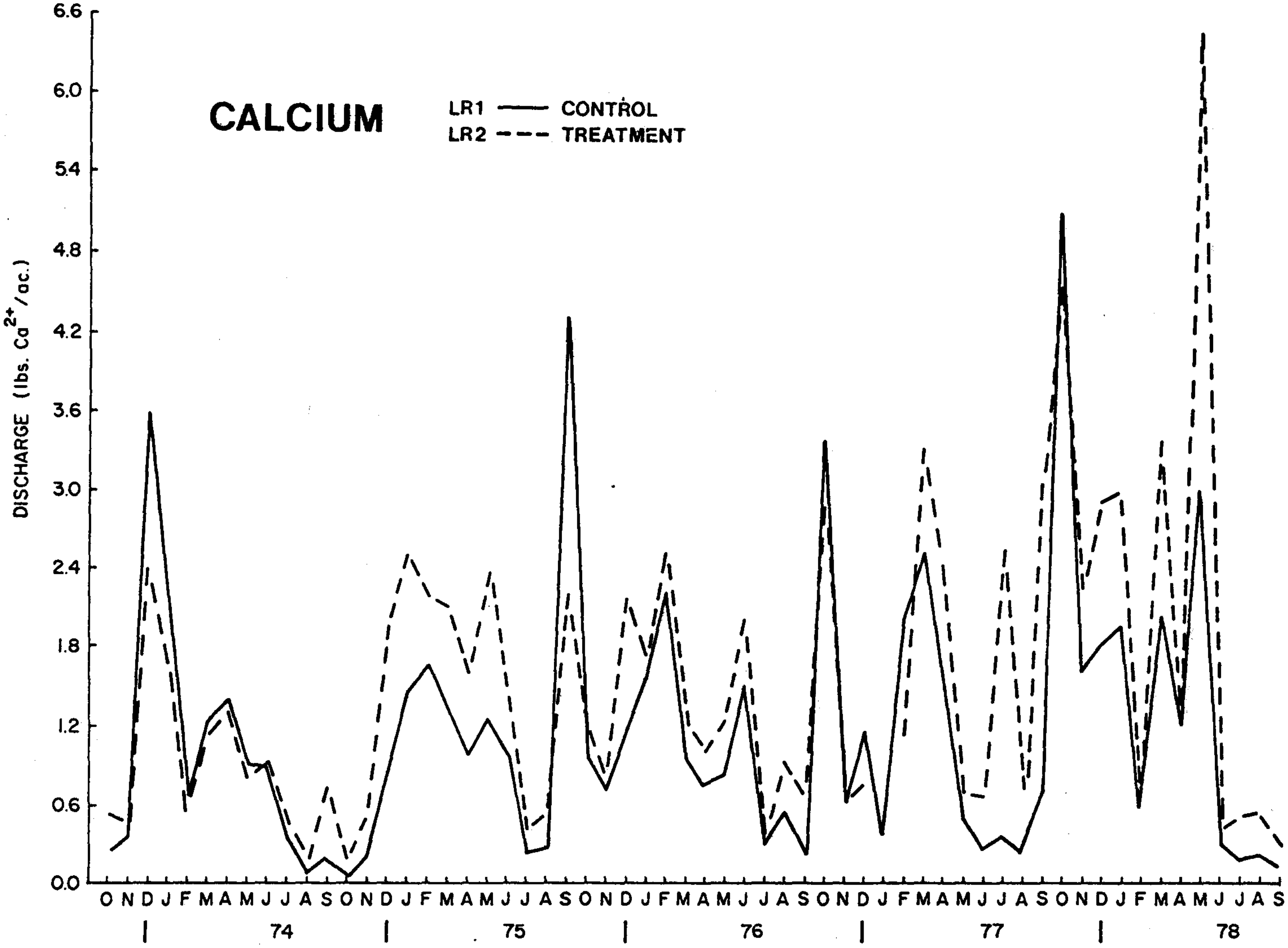


Figure 27. Average monthly calcium loading on the treated and control watersheds from October 1973 through October 1978.

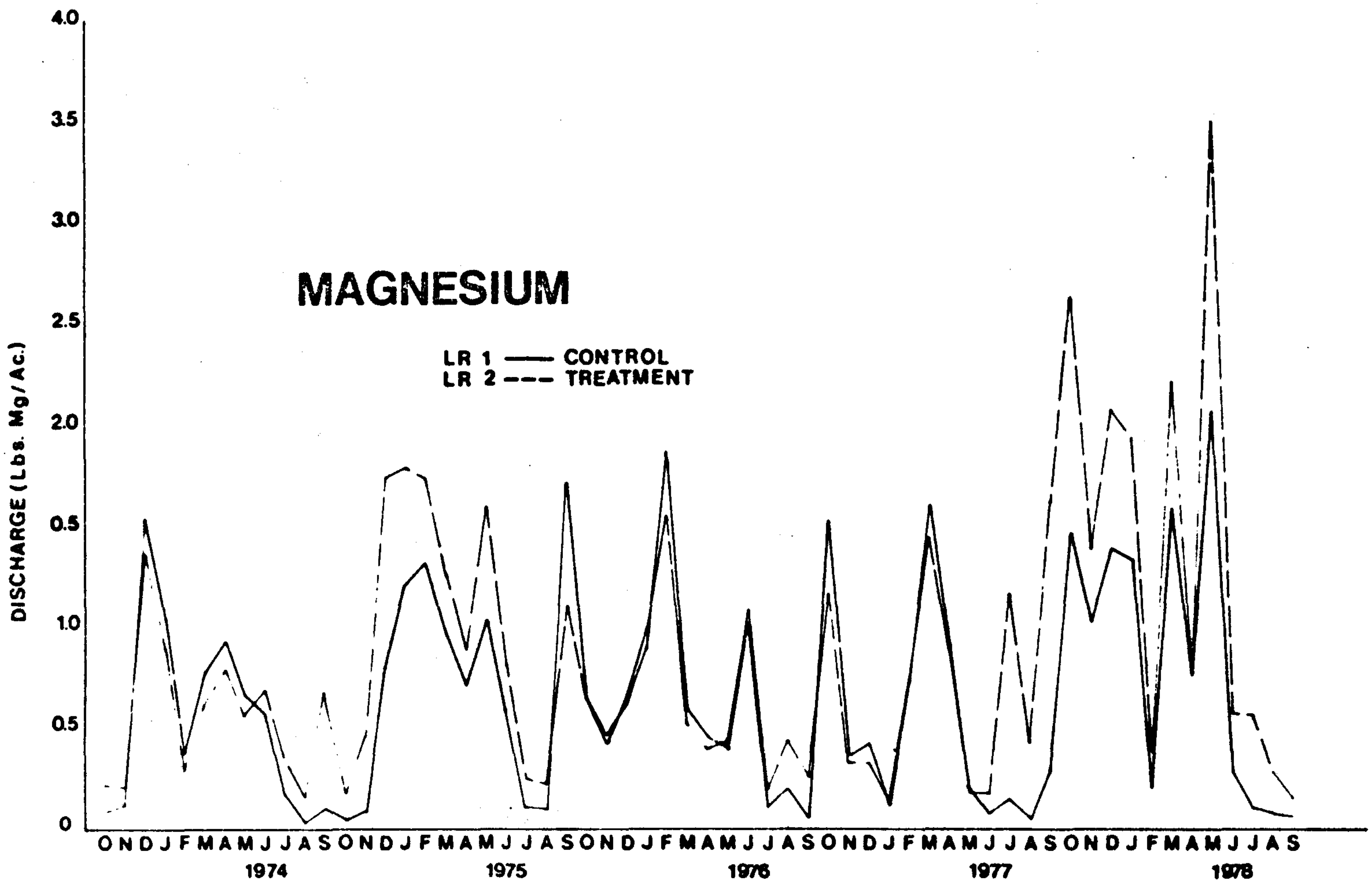


Figure 28. Average monthly magnesium loading on the treated and control watershed from October 1973 through October 1978.

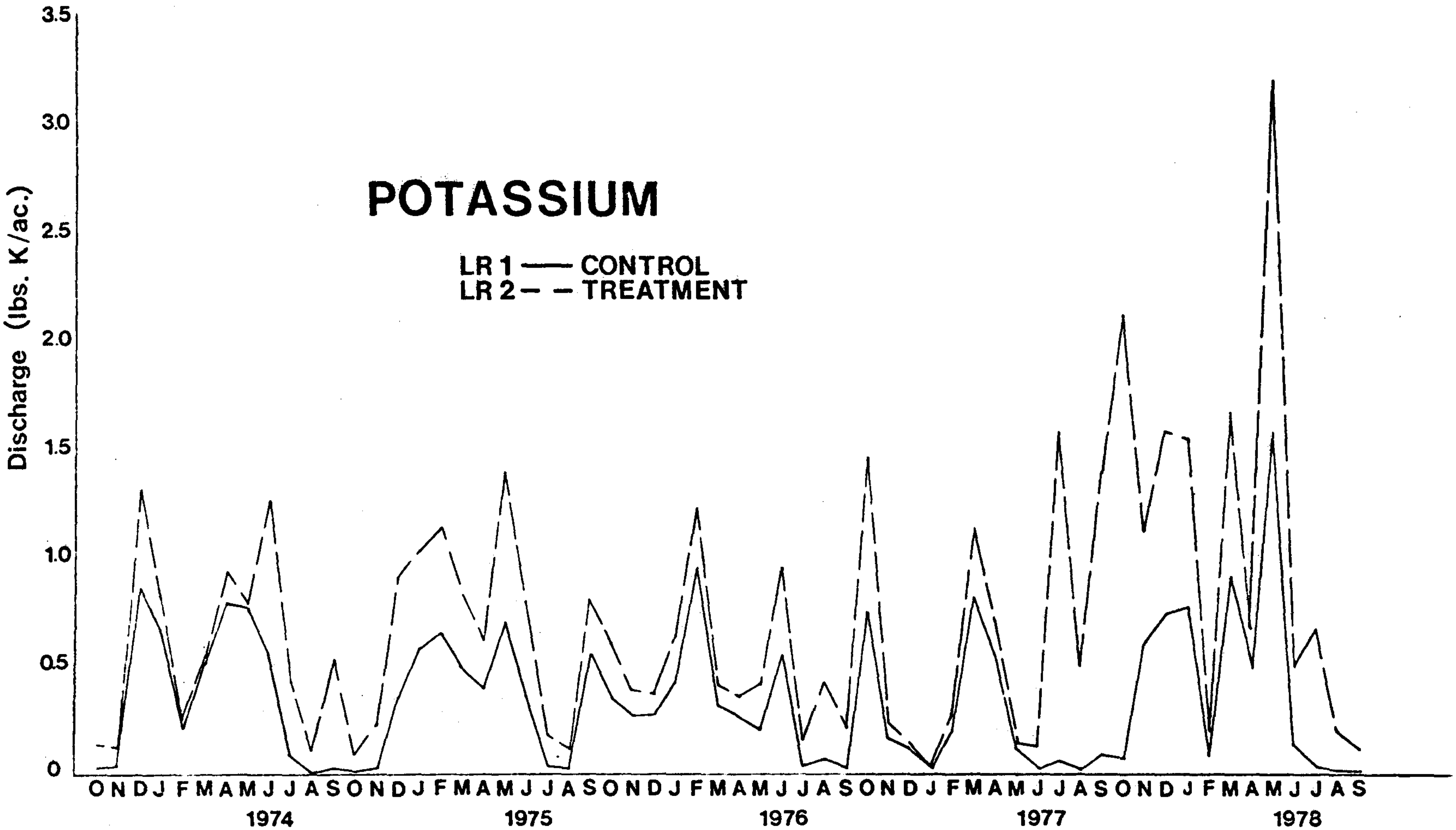


Figure 29. Average monthly potassium loading on the treated and control watersheds from October 1973 through October 1978.

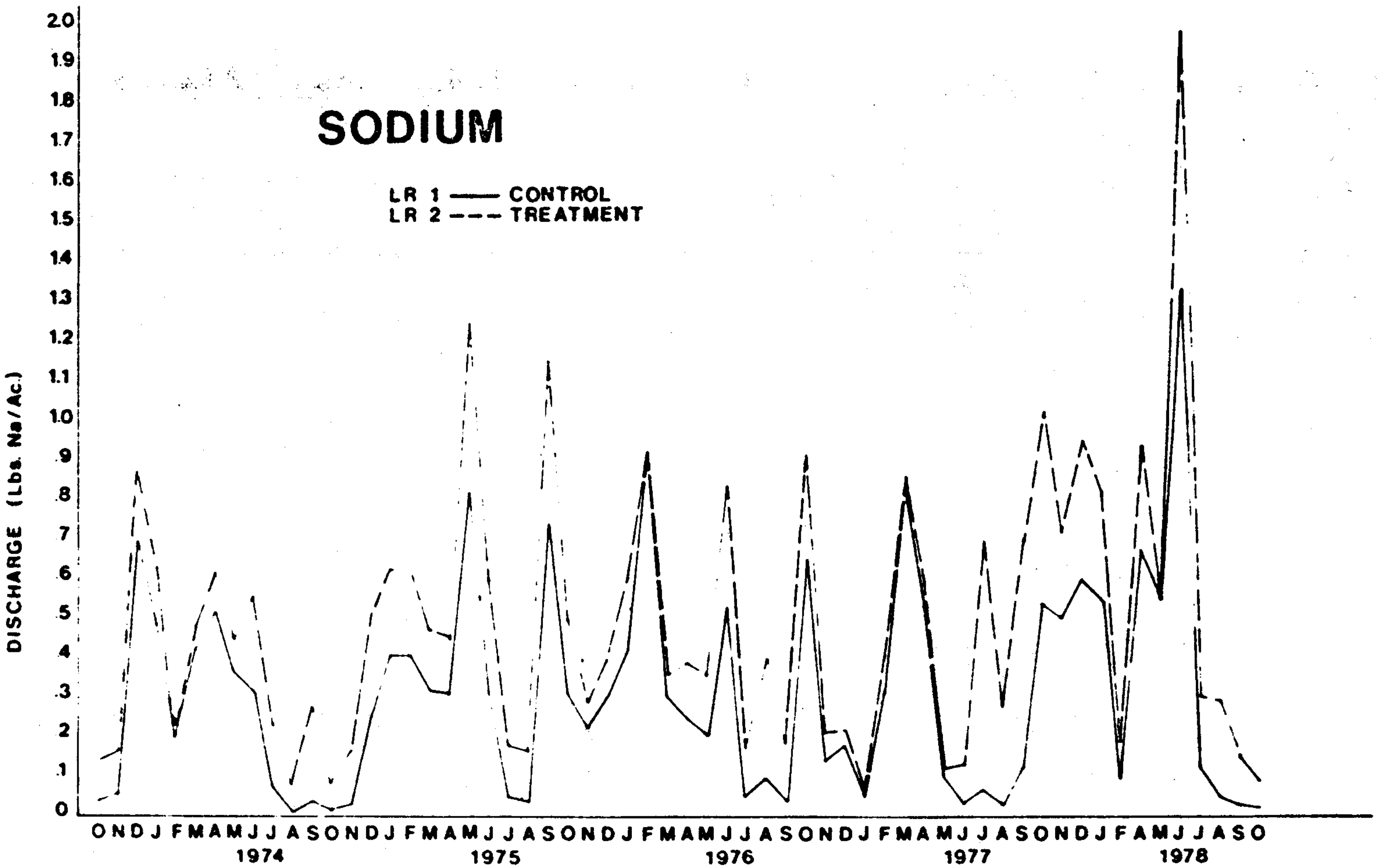


Figure 30. Average monthly sodium loading on the treated and control watersheds from October 1973 through October 1978.

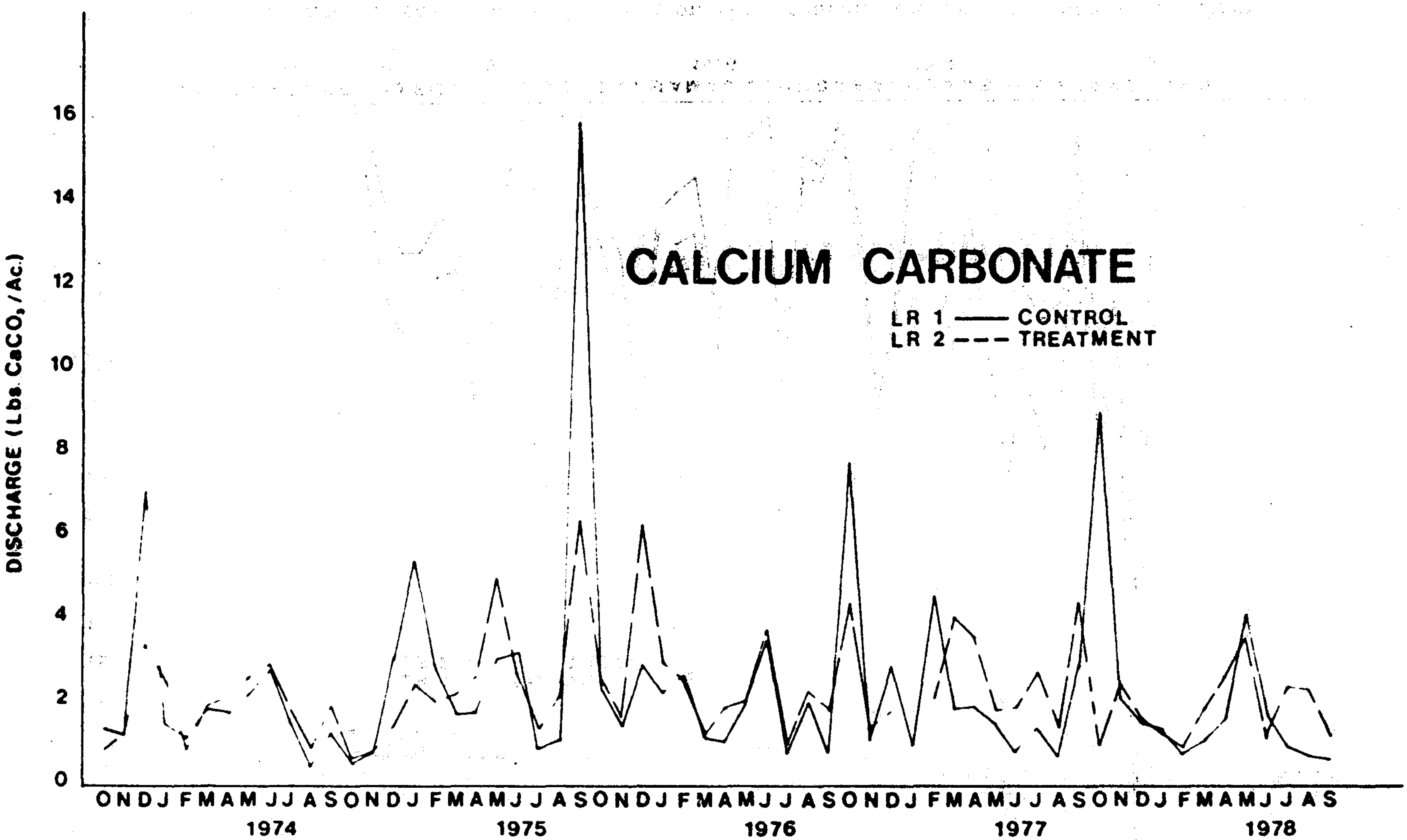


Figure 31. Average monthly calcium carbonate loading on the treated and control watersheds from October 1973 through October 1978.

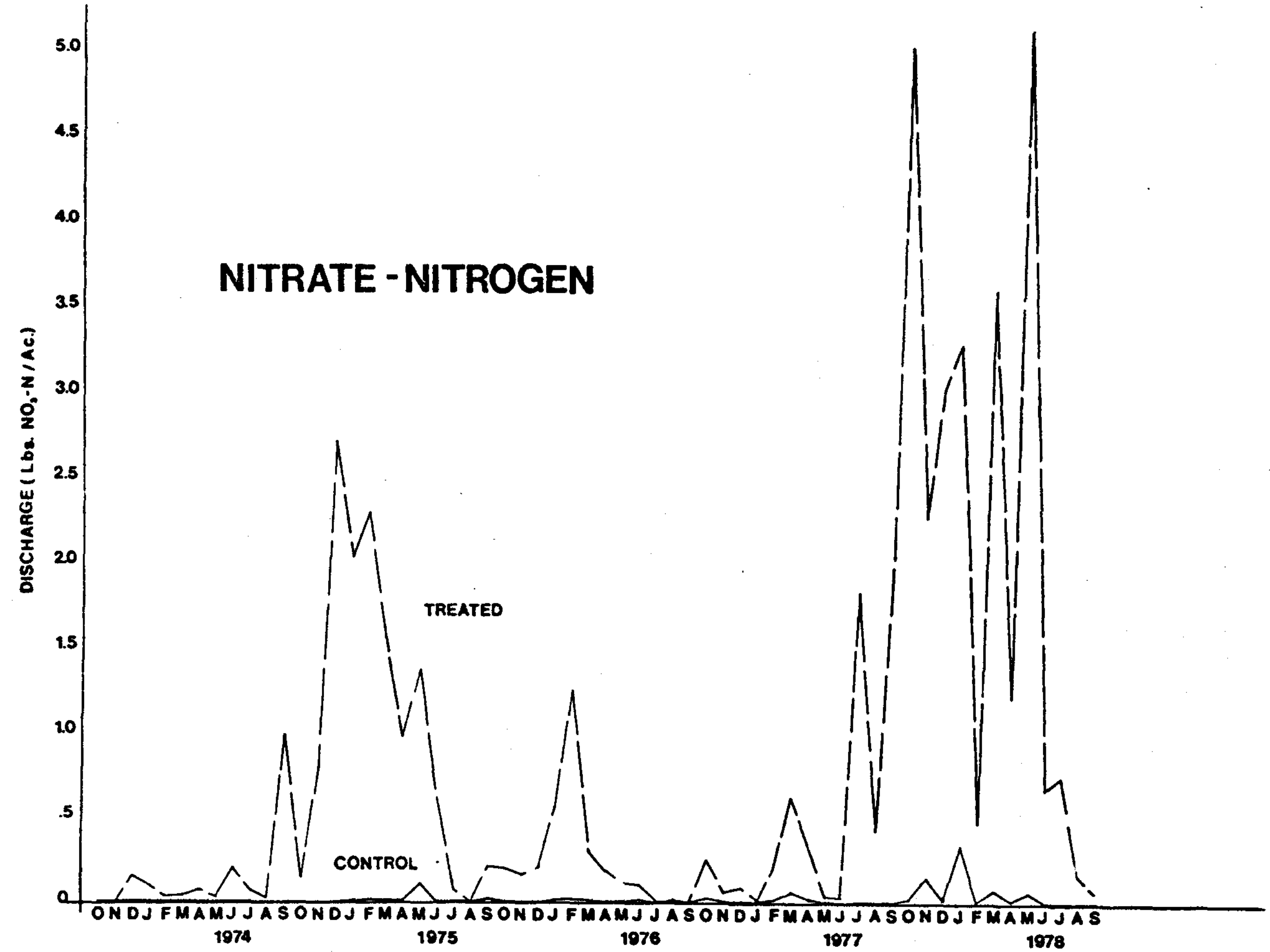


Figure 32. Average monthly nitrate-nitrogen loading on the treated and control watersheds from October 1973 through October 1978.

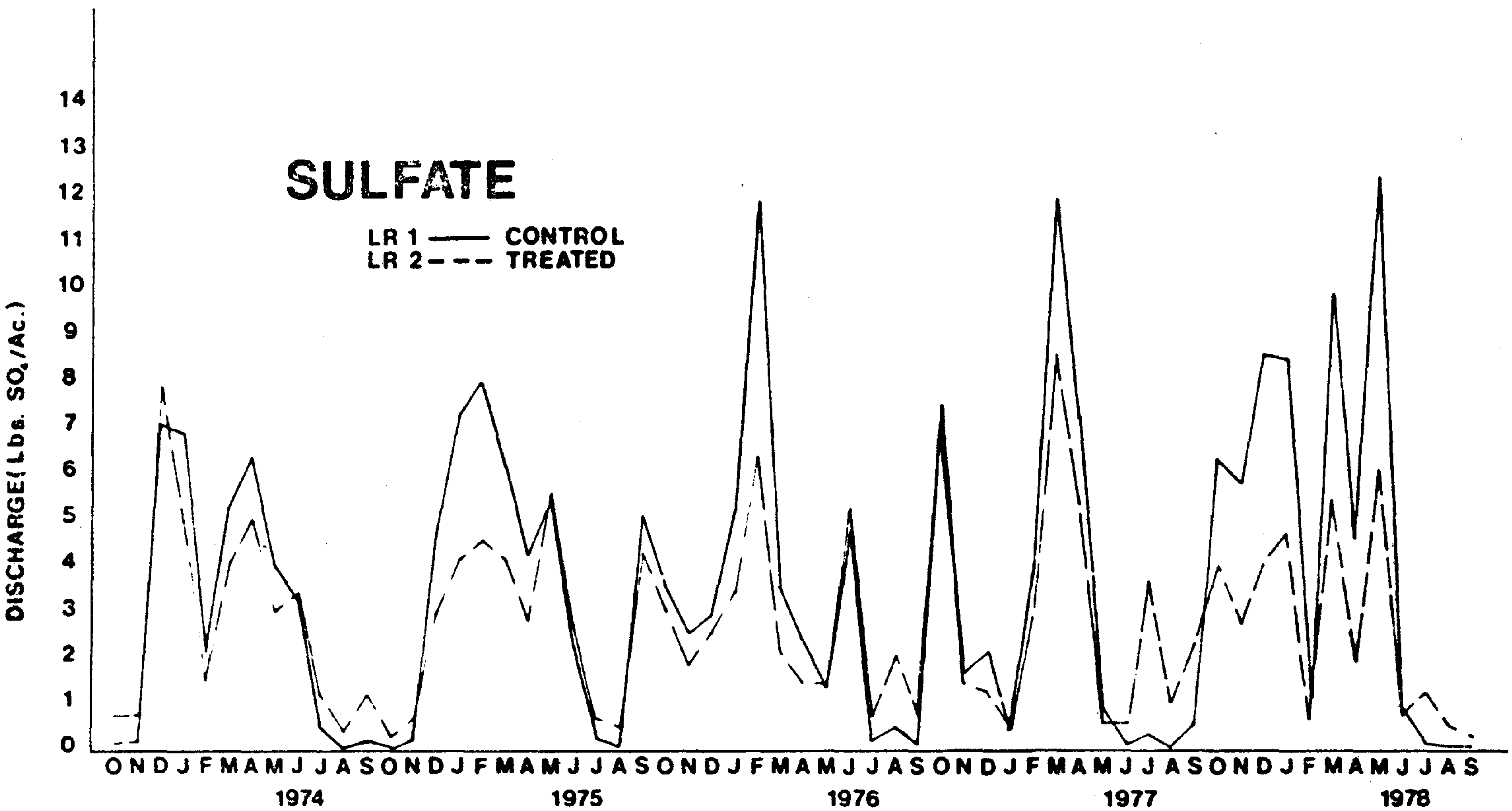


Figure 33. Average monthly sulfate loading on the treated and control watersheds from October 1973 through October 1978.

Table 23. Average nutrient loading (lbs/A) of streamwater for treated and control watersheds following the middle slope clearcut and herbicide treatment.

Nutrient	Watershed Control	Watershed Treated
Treatment/period: 48-acre clearcut/10-15-73 to 5-31-74		
Calcium	1.26	1.08
Magnesium	0.69	0.62
Potassium	0.49	0.63*
Sodium	0.35	0.45*
Calcium carbonate	2.22	2.03
Nitrate-nitrogen	<0.01	0.06*
Sulfate	4.09	3.56
Treatment/period: 48-acre clearcut-herbicided/6-1-74 to 5-31-75 (first year)		
Calcium	0.81	1.29*
Magnesium	0.59	0.96*
Potassium	0.33	0.73*
Sodium	0.25	0.45*
Calcium carbonate	2.11	2.08
Nitrate-nitrogen	0.01	1.11*
Sulfate	3.38	2.66
Treatment/period: 48-acre clearcut-herbicided/6-1-75 to 5-31-76 (second year)		
Calcium	1.29	1.28
Magnesium	0.70	0.67
Potsssium	0.35	0.54*
Sodium	0.34	0.49*
Calcium carbonate	3.09	2.79
Nitrate-nitrogen	0.01	0.33*
Sulfate	3.52	2.59

*Significant at 10 percent.

of these nutrients were not altered (Table 20). Potassium and nitrate-nitrogen loading also increased but these increases were attributed to both an increase in flow and an increase in concentrations. Average monthly export of sulfate and calcium carbonate did not appear to be affected by the herbicide treatment even though the concentrations of both nutrients were significantly lower. This would indicate that the decrease in concentration was a result of dilution caused by increased discharge.

During the second year following herbiciding, potassium, sodium, and nitrate-nitrogen loading remained higher on the treated watershed (Table 23); however, the magnitude of these increases was less than that of the preceeding year. Magnesium and calcium carbonate loading declined to near pre-herbiciding levels, while sulfate remained at about the same level. The lower loading rates were a result of a reduction in the water yield increase due to regrowth on the sprayed area and a decrease in the concentrations of some ions.

Average nutrient loading of streamwater for the treated and control watersheds the first year after completion of the upper slope and ridge top clearcutting are given in Table 24. Although the magnesium concentrations were significantly different in comparison to the control (Table 22) the total magnesium loading was not. The remaining nutrients did not appear to be affected by the additional cutting. However, following the application of herbicides to the entire 90-acre clearcut, the export of calcium, magnesium, potassium, sodium, and nitrate-nitrogen increased. The increase in calcium loading corresponded to a decrease in calcium concentrations on the treated watershed (Table 22). This would indicate that the decreased calcium concentrations were a factor of increased streamflow and resulting dilution and not an actual decrease in calcium leaching. This dilution effect was also evident for calcium carbonate. The increased loading of sodium and magnesium was a direct result of increased streamflow, while potassium and nitrate-nitrogen loading increases reflected an increase in both the amount of leaching caused by the elimination of the vegetation and an increase in stream discharge.

The overall effect of the clearcut-herbicide treatments on nutrient loading appeared to be a significant increase in the export of potassium and nitrate-nitrogen from the basin. Minor increases in calcium, magnesium, and sodium were also observed, while sulfate and calcium carbonate did not appear to be affected. Rapid revegetation of the site, a condition almost impossible to prevent in the humid East, generally prevented any major stream enrichment problems.

Table 24. Average nutrient loading (lbs/A) of streamwater for treated and control watersheds following the upper slope and ridge top clearcut and herbicide treatment.

Nutrients	Watershed	
	Control	Treated
Treatment/period: 90-acre clearcut/6-1-76 to 6-8-77		
Calcium	1.30	1.42
Magnesium	0.61	0.60
Potassium	0.29	0.50*
Sodium	0.30	0.42*
Calcium carbonate	2.48	2.55
Nitrate-nitrogen	0.02	0.15*
Sulfate	3.45	3.11
Treatment/period: 90-acre clearcut-herdicided/6-9-77 to 5-31-78		
Calcium	1.58	2.63*
Magnesium	0.87	1.52*
Potassium	0.52	1.33*
Sodium	0.43	0.75*
Calcium carbonate	2.28	2.14
Nitrate-nitrogen	0.06	2.37*
Sulfate	4.90	3.14*

*Significant at 10 percent.

IMPACT OF HERBICIDE TREATMENT ON MACRO-INVERTEBRATES

Treatment of the environment with chemicals is a common practice. Desirable objectives frequently require the immediate response that appropriate applications of chemicals can provide. Increased environmental awareness demands evaluation of the impact of chemicals applied to nontarget organisms.

Herbiciding the clearcut on the lower and middle slopes of Leading Ridge Two was done to control regrowth of vegetation while evaluating water yield and quality responses as various portions of the watershed were clearcut. The impact of the herbicide application on the stream draining the watershed and possibly its effects on the benthic macro-invertebrates were evaluated.

Herbicide was applied on June 3, 1974. The formulation included 1.5 gallon Weedone IBK (30%, 2,4,5 Trichlorophenoxyacetic acid, butoxyethanol ester; 31.2% 2,4 Dichlorophenoxyacetic acid, butoxyethanol ester; 38.9% Inert), 10 pounds Atrazine, 1 pint Trans-vert (51.9% monosodium acid methanearsonate). The area treated was 48 acres (45 percent of the watershed) on the lower and middle slopes of the watershed.

A 250 foot section of stream was sampled. Sampling was conducted at two times which bracketed the herbicide treatment of the watershed. Pre-treatment sampling was on May 31, 1974; post-treatment sampling was on June 12, 1974. A random starting point was chosen and 10 points upstream were marked at 25 foot intervals. Three 0.12 m^2 samples were collected at each point using a modification of the Hess type bottom sampler. Each sample was collected upstream from the previous one. A total of 30 samples were collected during each sample period.

Individuals per taxon, total number of individuals, and total number of taxa were counted for each sample; weight of crayfish, weight of other invertebrates, and $\bar{d}$ diversity were also measured. Counts and measurements for each of the three samples at a point were averaged and the mean used as a single sample. This procedure was used to reduce the variability which results from the contiguous distribution of benthic macro-invertebrates. There were effectively 10 samples for each collection date. Means from the pre-treatment collections were compared with post-treatment collections using a t-test to detect changes significant at the 95 percent level.

Significant decreases occurred in 11 of the 44 taxa collected during the 12-day interim between pre- and post-treatment samples. Nonsignificant decreases occurred in 27 additional taxa. There were also significant decreases in the mean numbers of individuals per sample and the mean number of taxa per sample. Nonsignificant decreases occurred in the mean weight per sample and mean diversity per sample.

The data would strongly support a herbicide treatment effect, except that a tenfold increase in the discharge of the study stream occurred on June 10, 1975. Discharge increased from an antecedent flow of 0.366 cubic feet per second per square mile (csm) to 3.64 csm. About 75 percent of this increase occurred in less than 45 minutes. While data documenting the depleting effects of this type of increased discharge on the benthic macro-invertebrates are meager, it is possible that depletion did occur as a result of increased discharge.

These data clearly indicate a depletion of the benthic macro-invertebrates between May 31, 1974 and June 12, 1974. It is not possible to determine the percentage of depletion due to herbicide treatment alone. Increased discharge, or a combination of factors including increased temperature, turbidity, or sediment loading as a result of the lower and middle slope clearcuttings may also have been contributing factors.

BIOLOGICAL IMPLICATIONS OF FOREST MANAGEMENT

The streams on the Leading Ridge Watershed Unit are characteristic of countless headwater streams throughout the Northeast. Such streams are clean, of inherent low fertility, and harbor fragile aquatic ecosystems. Invariably, these streams provide habitat for eastern brook trout (Salvelinus fontinalis) and other coldwater fish, the invertebrates on which they feed, and a limited variety of lower forms of plant life. These headwater streams provide a unique recreational resource and are held in high esteem by fishermen, water suppliers, and regulatory agencies.

By their very nature these fragile headwater streams can often be affected adversely by changes in several parameters associated with timber harvesting in general and clearcutting in particular. Some of the most significant parameters involved (1) water temperature, (2) turbidity and sediment loading (3) dissolved nutrients, and (4) streamflow.

Information exists that can be used to formulate the probable effects of timber harvesting on the aquatic environment. These probable effects are evaluated on the basis that each aquatic organism has a particular set of environmental conditions and habitat preferences that are optimal for its maintenance. Deviation from these optimal conditions puts stress on the organism and limits its reproduction, survival, growth, and population density.

Water Temperature

Water temperature is one of the major controlling factors of the aquatic environment. Since all aquatic organisms are poikilothermous (cold blooded), their body temperature is almost the same as that of their environment and is controlled by that environment. Aquatic plant communities are controlled, to a large extent, by the amount of light incidence on the water surface. The forest cover removal treatments described in this study caused higher water temperatures and increased the amplitude of the diel temperature fluctuation and incident sunlight on the stream of the treated watershed. As a result, the treatments may have had pronounced effects on the aquatic communities of this stream.

Aquatic Invertebrates

The aquatic invertebrate community is a vitally important link in the aquatic ecosystem. This community transfers energy from the primary producers, both within and outside the stream, to the secondary consumers, the fish. This community is very sensitive to changes in its environment.

Increases in stream temperature and light intensity such as occurred on Leading Ridge Two have a direct effect on the activities of aquatic insects. Holt and Waters (1967) determined that natural aquatic insect drift is controlled by light intensity. They found that even bright moonlight was sufficient to cause aquatic insects to discontinue natural drift during nocturnal periods.

Wojjalik and Waters (1970), while investigating the direct effect of heated water on aquatic insects, found that as the thermal differential of an experimental stream increased, the drift rate of the mayfly Baetis vagans increased to the point where a serious reduction, approaching complete depletion in standing crop of this species, occurred. An increase in thermal differential occurs in streams exposed to direct solar radiation, such as was the case on Leading Ridge Two. Since all species of aquatic invertebrates have a specific thermal tolerance range, the increase in temperatures on Leading Ridge Two would undoubtedly change the community structure. Changes in community structure could also occur due to the increase in diel stream temperature fluctuation.

Subtle indirect effects of stream temperature increases include the decrease in dissolved oxygen concentrations that occur in streams when riparian vegetation is removed (Burns, 1972). Exposure of headwater streams such as Leading Ridge Two to direct solar radiation results in elevated temperatures which decrease the water's capacity to hold dissolved oxygen. A small change in dissolved oxygen levels can be of major importance to aquatic organisms. Nebecker (1972) observed the effect of reduced oxygen concentrations on an aquatic community and found that "safe" concentrations of dissolved oxygen for survival and adult emergence of larvae of nine species of aquatic insects (mayflies, stoneflies, caddisflies, and midges) ranged from 0.6 mg/l for the midge Tanytarses dissimilis to 9.0 mg/l for emergence of the may fly Ephemera simulans. He showed that the ability of insects to survive low oxygen concentrations (90 percent of E. simulans survived 4.0 mg/l for 96 hours) does not mean they can successfully mature, emerge, and reproduce. No adult of E. simulans emerged after being exposed to 4 mg/l concentrations of dissolved oxygen.

The change in the stream temperature regime on Leading Ridge Two as a result of treatment could have drastically changed the aquatic invertebrate community of that stream by killing, causing drift out of the area, or disrupting emergence, maturing, or reproduction of some of the insects present. A change in the primary production could also have had an effect on the structure of the aquatic invertebrate community.

Fish

The effect of forest cover removal on fisheries has received little attention in the eastern United States. Information is available on the effects of environmental changes on fish, hence probable effects of temperature increases, for instance, can be determined.

Each species of fish has a particular set of environmental conditions and habitat preferences optimal for its maintence. Deviation from these optimum conditions put stress on the fish and limits its reproduction, survival, growth, and population density. Each species of fish has upper and lower lethal temperature limits. Temperature sets limits on a fish's life; however, through gradual acclimation, they can withstand temperatures which, if encountered rapidly, would be lethal (Fry, 1947).

The family to which trout belong, Salmonidae, tolerate temperatures as low as 32°F and maximums barely exceeding 77°F (Brett, 1956). The eastern brook trout is least tolerant to warm temperatures. Mortality occurs in less than 30 minutes at a temperature of 84°F (Hesser et al., 1975). Brook trout can tolerate temperatures near 32°F; however, their optimum is 60 to 68°F, and water temperatures warmer than 70°F cause stress. Stream temperatures on Leading Ridge Two have exceeded the lethal limit of brook trout, 84°F, on several occasions as a result of treatment. Stream temperatures exceeded 70°F almost every day during the summer on this stream. These two facts would probably be enough to preclude brook trout from this stream.

Hesser et al. (1975) report that spawning by brook trout occurs as the result of decreased photoperiod and is triggered by a temperature of approximately 40°F. Incubation periods vary from 146 days at 35°F to 44 days at 50°F. High mortality occurs if incubation takes place in water temperatures above 54°F. An increase in incubation temperature of 1°F may cause the eggs to hatch a week sooner. Fall stream temperatures on Leading Ridge Two when brook trout spawn, were different from those of the control. Maximum stream temperatures were higher and in some cases exceed 54°F even in November. Minimum stream temperature regime would certainly have an effect on brook trout reproduction, but exactly what that effect would be would require further study.

Fish have the ability to acclimate to fluctuating temperatures. Brett (1952) conducted laboratory tests on the acclimation abilities of various Salmonids. His results may be more applicable on large streams where incremental temperature changes affecting large volumes occur than on small streams where large diel temperature fluctuations can occur (Lantz, 1971). On Leading Ridge Two diel fluctuations of up to 31°F were recorded compared to a maximum of 10°F on the

control. On the positive side, it is likely that such fluctuations beginning early in the year can help acclimatize fish to higher temperatures more rapidly than they would become without the fluctuations. On the negative side, it is also likely that fish may experience more difficulty adjusting to decreasing rather than increasing temperatures. Also, the large diel fluctuations which occurred in the spring on Leading Ridge Two may simply be more than the fish could cope with. Lethal temperature effects must be considered both in terms of the thermal level and the exposure time.

Fish are able to sense temperature changes as slight as 0.1°F (Bardach and Bjorklund, 1957). Such small temperature changes, common as thermal background noise, are ordinarily ignored unless they become meaningful. However, such sensitivity enables fish to follow a temperature gradient toward their preferred temperature. Such movement could result in migration of brook trout from a warmed stream. Heating of a stream could also result in other less desirable species moving into an area and competing with native species (Chapman, 1962). Investigations by the Pennsylvania Fish Commission have confirmed that brown trout Salmo trutta, require slightly warmer temperatures than brook trout, and if heating of headwater streams were to occur they may complete with brook trout for available space (Hesser et al., 1975).

The removal of riparian vegetation, such as on Leading Ridge Two, greatly increases light intensity which can result in deterioration of trout habitat. Fry (1951) reported that brook trout avoid exposure to full sunlight but on the other hand are quiescent during hours of darkness. A trout's preference apparently lies somewhere between these two extremes, because shade patterns on the stream bottom are utilized as a type of cover.

Increase in stream temperature not only affect fish directly but can also indirectly affect their well being by reducing the available dissolved oxygen content of the water and reducing the disease resistance of the fish. Increased temperatures cause fish to have a higher oxygen demand because of increased metabolic activity of the fish, but at the same time, the water can hold less dissolved oxygen (Cairns, 1970, and Narver, 1971). In studies carried out with salmonids, higher water temperatures drastically increased the effects of kidney diseases, furunculosis, vibrio disease, and columnaris disease. It was found that strains of columnaris reached epidemic proportions when water temperatures exceeded 70°F, but mortalities diminished or ceased when water temperatures were reduced to 65°F or lower (Ordal and Pacha, 1963). Whether or not dissolved oxygen levels or diseases would be a problem as a result of treatment such as was done on Leading Ridge Two cannot be evaluated just by looking at the temperature regime, but the potential would be there because of the dramatic increase in stream temperatures that occurred.

The clearcut-herbicide treatment resulted in dramatic changes in the temperature regime of Leading Ridge Two. This temperature regime would most certainly have a negative effect on the aquatic invertebrates and the fish life of this stream. The high maximum and minimum temperatures, large diel fluctuations, and long durations of time above set temperature limits all could be lethal to various aquatic organisms, including brook trout. At the very least, the aquatic community of this stream would be drastically changed.

Stream Turbidity and Sediment Loading

Accelerated erosion and sedimentation can lead to many environmental consequences. Major problems include reduction in reservoir storage and stream channel water-carrying capacities, water quality impairment and health hazards, increased cost of water treatment and a reduction in the hydrologic amenities. There are also many impacts on the aquatic ecosystem. The impact of the increased turbidity and sediment on Leading Ridge Two on aquatic organisms was not studied. Nevertheless, information exists that allows the estimation of probable effects. It is known that turbid water blocks light transmission, reducing the visual feeding range of fish and the primary production of aquatic plants. The effects on primary productivity and food organisms upon which fish survival depends may be more harmful than the direct effects of turbidity on adult fish (Hesser *et al.*, 1975).

Fine sediments can cause inflammation of the gill membranes and eventual death for young fish. Fish culturists report that fry and fingerling trout reared in turbid water are more prone to bacterial gill infections. Silt acts as a substrate for the bacteria and when it adheres to the mucous on the gill, infection can develop rapidly.

Sedimentation reduces cover by filling pools and producing a uniform substrate offering little shelter. A significant relationship exists between the size of trout populations and the quality of cover in streams (Boussu 1954; Hunt 1969; Stewart 1970). Sedimentation from soil disturbances on watersheds supporting trout streams and subsequent changes in stream morphology have deteroirated more trout habitats than any other single influence (Hesser *et al.*, 1975).

The deposition of sediment on spawning areas suffocates eggs, embryos, and alevins by filling the intersticial spaces in gravel, thereby reducing the flow of water containing oxygen. Streams with significant sedimentation are generally low in productivity when compared to similar streams subjected to smaller amounts of sediment (Hesser *et al.*, 1975). In addition, organic sediments require oxygen for decomposition, thereby reducing that available for respiration of organisms.

Sediment and turbidity also have a detrimental effect on aquatic insects. Turbidity has been cited as the cause of increased drift rates in some organisms (Pearson and Franklin 1968). Apparently, physical abrasion by the transported particles damage benthic organisms and can cause them to release from the substrate. The light-scattering properties of turbidity also could result in increased drift rates. Many organisms have a positive activity response to decreases in light intensity.

Sedimentation is also destructive of aquatic insect habitat. Sand, silt, and clay are easily transported and are poor substrate for insect colonization. A significant relationship exists between decreasing substrate particle size and decreases in numbers of organisms occupying that substrate in lotic environments (Scott 1966).

Turbidity created during timber harvesting operations may affect the aquatic biota downstream beyond the clearcut area. It would remain a significant periodic problem in the receiving stream for several years following harvesting if skid trails and logging roads are not retired properly.

Dissolved Nutrient Concentrations

While water turbidity and temperature continue to be important water quality problems, much concern has been expressed over nutrient losses following timber harvesting operations. The accelerated loss of nutrients following forest cutting might adversely affect stream water quality, resulting in accelerated eutrophication.

Nutrient losses after clearcutting on the Leading Ridge Experimental Watershed seem to be negligible. Although temporary enrichment of streamflow was noted, this stream enrichment was not enough to cause eutrophication. In some cases enrichment of streams may be beneficial, particularly in streams that are relatively devoid of dissolved nutrients in their natural state. These increased nutrients in streamwater may support plant and animal life previously nonexistent or existing at low population levels (Pierce *et al.*, 1972). The magnitude of any nutrient increase would dictate whether or not the higher forms, including trout, would be affected. In any event, if a nutrient increase did occur, its importance would decline as revegetation of the cutover area occurs.

Streamflow

Increases in stream discharge resulting from reduced evapotranspiration in cutover areas can be both beneficial and detrimental to the aquatic biota. Greater stream discharges during critical summer low flow periods as noted on the treated watershed, should result in increased survival and growth of trout (Packer 1957). There is clearly a positive correlation between annual water yield and standing stock of trout (White 1972; Latta 1965).

The increase in stream discharge is related to the percent of the watershed that has been treated. Where the percent of watershed treated is relatively small, the increase in low flow discharge would be negligible. Where a large percentage of the watershed has been treated, other detrimental effects of clearcuts on the aquatic environment might offset advantages realized through increased low flow discharges.

The effects on the aquatic community of changes in peakflow rates and stream velocity characteristics due to timber harvesting have not been well quantified. Increases in peak discharge from storm runoff coupled with a decrease in time to peak and longer time of storm recession will increase and prolong higher stream velocities. Increases in the velocity of streams are of great importance to the stability of the benthic community. As velocity increases, a corresponding larger portion of the substrate can be transported and scoured, resulting in a larger number of benthic organisms being dislodged. If the frequency and intensity of increased discharges are great enough the benthic community can be depressed to lower densities (Hoopes 1975; Tebo 1955). In addition, an increase in stream discharge from storm runoff can cause the substrate to shift and eventually destory sensitive trout eggs and embryos.

Whether the effects of increased streamflow resulting from timber harvesting are detrimental or beneficial, the overall effects would tend to be short-term as the cutover area revegetates and increased water yields return to precutting levels.

SUMMARY

Evaluation of the Leading Ridge Two experimental treatments have shown that removal of the forest cover and herbiciding to restrict regrowth of both herbaceous and woody vegetation can substantially increase stream temperatures, discharge, turbidity, and sediment loading, and also result in alteration of the normal patterns of nutrient cycling. It is also evident that these increases, particularly the changes in nutrient cycling, are moderated considerably with the establishment of a vegetative cover (herbaceous or woody) on the cutover area, a condition that is almost impossible to prevent in the humid East.

The Leading Ridge Two Experiments represent the maximum effects of vegetation removal on the quantity and quality of streamflow draining a forested watershed. Because of the use of herbicides in controlling regrowth -- a practice not performed on commercial clearcuts in Pennsylvania -- these data should not be extrapolated to represent the hydrologic response to a commercial clearcut.

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